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EVALUATION OF THREE-PIECE AM2 ALUMINUM LANDING MAT

by

W. N. Brabston

April 1967

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MP 4-615	Development of CBR Design Curves for Harvey Aluminum Landing Mat (AM2)	Jan 1964
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MP 4-655	Development of CBR Design Curve for Modified AM1 Landing Mat	June 1964
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MP 4-789	Evaluation of Butler AM2 Landing Mat	Feb 1966
MP 4-850	Evaluation of Guide Rail in Conjunction with Kaiser and Harvey Landing Mat (AM2)	Oct 1966
MP 4-852	Evaluation of Harvey Two-Piece Landing Mat (AM2)	Nov 1966

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13. ABSTRACT

This investigation was conducted to evaluate three-piece AM2 landing mat extruded by the Michael Flynn Manufacturing Company, Philadelphia, Pa., and fabricated by the Washington Aluminum Company, Enterprise, Ala. The mat was fabricated from three 8-in.-wide extrusions welded together to form a 2-ft-wide plank. A test section consisting of one sand item and three clay subgrade items with various CBR strength values was constructed and surfaced with the three-piece mat. The test section was subjected to uniform-coverage and single-line traffic representing operations of an aircraft having a 60,000-lb gross weight with a single-wheel main gear assembly load of 27,000 lb with a 30-7.7 tire inflated to 400 psi. Based on the results obtained in this study, it is concluded that: (a) When placed on a subgrade having a CBR of 6.8 or greater throughout the period of traffic, the three-piece mat will sustain 1600 cycles (188 coverages) of an aircraft having a 27,000-lb single-wheel load and a 400-psi tire-inflation pressure. (b) The three-piece mat will sustain 1600 passes (in a single path located 2 ft or more from the mat end joints) of a 27,000-lb single-wheel load with a tire-inflation pressure of 400 psi when placed on a subgrade having a CBR of 5.7 or greater throughout the period of traffic. (c) General behavior of the mat in these tests was not materially affected by the three-piece nature of the mat planks.

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FOREWORD

This report is the 15th in a series published on landing mat tests performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Naval Air Engineering Center (NAEC), Philadelphia, Pa. (formerly the Naval Air Material Center (NAMC)). The investigation reported herein was authorized by the NAEC in Project Order No. 6-4031, dated 3 December 1965, and was conducted by the WES during March 1966.

Engineers of the Soils Division who were actively engaged in the planning, testing, analyzing, and reporting phases of the investigation were Messrs. R. G. Ahlvin, C. D. Burns, W. N. Brabston, and M. J. Mathews under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, respectively, of the Soils Division. The report was prepared by Mr. Brabston.

COL John R. Oswalt, Jr., CE, was Director of the WES during the conduct of the investigation and preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
square feet	0.092903	square meters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
kips	453.59237	kilograms

SUMMARY

This investigation was conducted to evaluate three-piece AM2 landing mat extruded by the Michael Flynn Manufacturing Company, Philadelphia, Pa., and fabricated by the Washington Aluminum Company, Enterprise, Ala. The mat was fabricated from three 8-in.-wide extrusions welded together to form a 2-ft-wide plank.

A test section consisting of one sand item and three clay subgrade items with various CBR strength values was constructed and surfaced with the three-piece mat. The test section was subjected to uniform-coverage and single-line traffic representing operations of an aircraft having a 60,000-lb gross weight with a single-wheel main gear assembly load of 27,000 lb with a 30-7.7 tire inflated to 400 psi.

Based on the results obtained in this study, it is concluded that:

<u>a</u>. When placed on a subgrade having a CBR of 6.8 or greater throughout the period of traffic, the three-piece mat will sustain 1600 cycles (188 coverages) of an aircraft having a 27,000-lb single-wheel load and a 400-psi tire-inflation pressure.

<u>b</u>. The three-piece mat will sustain 1600 passes (in a single path located 2 ft or more from the mat end joints) of a 27,000-lb single-wheel load with a tire-inflation pressure of 400 psi when placed on a subgrade having a CBR of 5.7 or greater throughout the period of traffic.

<u>c</u>. General behavior of the mat in these tests was not materially affected by the three-piece nature of the mat planks.

EVALUATION OF THREE-PIECE AM2 ALUMINUM LANDING MAT

PART I: INTRODUCTION

Background

1. For several years the U. S. Army Engineer Waterways Experiment Station (WES) has been engaged in a study for the Naval Air Engineering Center (NAEC), Philadelphia, Pa., to evaluate various types of landing mats to be used in surfacing small airfields for tactical support (SATS) in combat air operations. A SATS has been defined as a small, quickly constructed, temporary, tactical-support airfield capable of sustaining operations of the Marine Corps' modern jet aircraft which employ assisted takeoffs and arrested landings.

2. The service criterion established by NAEC for landing mat is that it remain in serviceable condition with minimum maintenance for at least 1600 aircraft operation cycles during a 30-day period when supported on a subgrade having a CBR of 10 or less. (A cycle is one takeoff and one landing.) The heaviest fighter aircraft utilizing SATS at the present time has a gross weight of 60,000 lb,* or a main gear wheel load of 27,000 lb. The aircraft is equipped with 30-7.7, 18-ply rating tires inflated to 400 psi. In the evaluation of various landing mats which have been considered for use on SATS, NAEC has standardized the test load and tire at a 27,000-lb single-wheel load on a 30-7.7, 18-ply tire inflated to 400 psi. Test criteria established by NAEC are that a test section of the particular mat under consideration remain serviceable with minimum maintenance for (a) 188 coverages (equivalent to 1600 cycles) of the test load applied uniformly over a 10-ft-wide traffic lane when supported on a subgrade having a CBR of 10 or less, and (b) 1600 passes of the test load applied in a single path (one tire-print width) supported on the same subgrade. The uniform-coverage traffic is to simulate landings and normal takeoffs (takeoffs in which no catapult is used), and the

* A table of factors for converting British units of measurement to metric units is presented on page vii.

single-line traffic is to simulate takeoff runs in which a catapult system is employed.

3. Early in the test program, an aluminum landing mat developed by the Harvey Aluminum Company (hereafter referred to as Harvey), Torrance, Calif., and tested at the WES, fulfilled the test requirements noted above. A description of the mat, the tests, and the test results was published in 1964.* Subsequently, the Harvey mat design was standardized by NAEC, and the mat was designated "Airfield Matting No. 2" (AM2). Several tests have been conducted at the WES on small quantities of AM2 fabricated under different procurement contracts (see report titles on the inside of front cover of this report). Although there has been considerable variation in the test performance of the AM2 fabricated by the various manufacturers, all the mats tested met minimum performance standards. The results of a later test with Harvey AM2 utilizing a modified end-joint connector indicated that the modified mat was superior to the AM2 previously standardized. Therefore, NAEC incorporated the modified joint detail in the specifications for future AM2 procurements.

4. The Harvey AM2 was constructed from a single aluminum extrusion approximately 2.05 ft wide that was cut into 12-ft lengths. End-joint connectors were welded onto each 12-ft length to form a plank. Although the single extrusion process facilitates plant fabrication of the mat, the number of manufacturers in the United States capable of producing extrusions of this size is quite limited. Therefore, the NAEC procured and the WES tested small quantities of AM2 fabricated by welding together several narrow aluminum extrusions. The multiextrusion mat requires a more complicated manufacturing process than the single-extrusion AM2, but a greater number of manufacturers have the capability of producing the narrow extrusions and thus this design potentially increases the sources of AM2.

5. The AM2 used in this investigation was fabricated from three

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* U. S. Army Engineer Waterways Experiment Station, CE, Development of CBR Design Curves for Harvey Aluminum Landing Mat (AM2), by C. D. Burns and W. B. Fenwick, Miscellaneous Paper No. 4-615 (Vicksburg, Miss., January 1964).

8-in.-wide by 12-ft-long extrusions welded together to form a single 2- by 12-ft plank. The extrusions were manufactured by the Michael Flynn Manufacturing Company, Philadelphia, Pa., and the planks were fabricated by the Washington Aluminum Company, Enterprise, Ala. (WACO).

Objective and Scope of Investigation

6. The objective of this investigation was to evaluate the performance of WACO three-piece AM2 under accelerated traffic tests with loadings contemplated under the SATS concept.

7. The objective was accomplished by:

   a. Constructing a test section that consisted of different subgrade materials and strengths and surfacing the section with WACO three-piece, aluminum landing mat.

   b. Performing accelerated traffic tests with a 27,000-lb single-wheel load on a 30-7.7, 18-ply rating tire inflated to 400 psi.

   c. Observing the behavior of the mat and subgrade during trafficking and recording pertinent test data.

   d. Comparing and analyzing the performance and data from the WACO mat test with the criteria established by NAEC for AM2.

This report includes a description of the landing mat, test section, tests conducted, and results obtained, and an analysis of the test data.

Definition of Traffic Terms

8. Various traffic terms used in this report are defined below:

   a. Cycle. A cycle is one takeoff and one landing of an aircraft. For this test, a cycle is considered to be one round trip or two passes on a runway or taxiway.

   b. Pass. A pass is one traverse of a load wheel along a given length of runway, taxiway, or test section surface. In this investigation load repetitions applied in a single path (one tire-print width) are referred to as passes. The repetitious loads resulting from aircraft taking off over the same path when using a catapult system are simulated on a test section by the application of the test load in repeated passes along a single line or path, e.g. 1600 cycles of an aircraft involve 1600 takeoffs or passes over the same path.

c. Coverages. One coverage consists of one application of the wheel of an aircraft or test load vehicle over the entire area within the limits of the test lane being subjected to traffic. Since the traffic is applied incrementally in passes, and the width of each pass is equal to one tire-print width, the number of passes required to complete one coverage is equal to the test lane width divided by the tire-print width.

PART II: TEST SECTION, MAT, AND TEST LOAD CART

Test Section

Location

9. The traffic tests were conducted at the WES on a special test section which was constructed and trafficked under shelter in order that water content and strength of the subgrade soil could be controlled.

Description

10. A layout of the test section is shown in plate 1. The test section was approximately 150 ft long and 24 ft wide and consisted of four test items. Items 1, 2, and 3 were approximately 40 ft long, and item 4 was approximately 30 ft long. The subgrades of items 1, 2, and 3 were constructed of a heavy clay soil, and the subgrade of item 4 was constructed of a loose sand. Classification data for the subgrade soils are shown in plate 2. All items were surfaced with WACO three-piece AM2.

Subgrade construction

11. The test section was originally constructed for the Harvey two-piece AM2 tests. A description of the test section is contained in WES Miscellaneous Paper No. 4-852.* In both the two- and three-piece AM2 tests, the desired subgrade strengths of items 1, 2, and 3 were 3, 6, and 10 CBR, respectively, and the subgrade of item 4 was constructed to simulate a natural sand with little or no compaction. In-place CBR tests conducted after the Harvey two-piece mat traffic tests indicated that the strengths of items 1, 2, and 3 were sufficiently close to the desired values that the subgrade could be used for the WACO three-piece mat test with a minimum of reconstruction. Reconstruction effort on items 1, 2, and 3 consisted of scarifying and recompacting the top 6 in. of soil and then fine-blading the surface to the desired grade with a motor patrol. Since the sand in item 4 had densified under previous traffic, it required loosening to obtain the desired condition.

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* U. S. Army Engineer Waterways Experiment Station, CE, Evaluation of Harvey Two-Piece Landing Mat (AM2), by C. D. Burns and W. C. Barker, Miscellaneous Paper No. 4-852 (Vicksburg, Miss., November 1966).

The sand was loosened with a front-end loader and then graded with a D-4 tractor.

Mat

Description

12. The AM2 planks were fabricated from three 12-ft-long, aluminum extrusions, each approximately 8 in. wide, which were welded together to form a single plank with an overall width of 2.06 ft. The nominal overall length of a full-size plank with end connectors is 12.08 ft. The mat is also made in half-size planks so that the planks can be placed in a staggered-joint configuration as shown in plate 1. The nominal dimensions of the half-size planks are 6.08 by 2.06 ft. The nominal thickness of the mat is 1.5 in. The top surface of each plank is coated with an antiskid compound. Fig. 1 shows one full- and one half-size plank, and fig. 2 shows a cut section of mat. The planks were packaged in bundles of 11 full- and 2 half-size planks; each bundle weighed approximately 2056 lb. Thirteen bundles of mat were received at the WES.

Placement procedures

13. The mat was placed on the test section by a crew of seven experienced laborers under the supervision of a foreman. The mat bundles were placed alongside the test section with a forklift, and the individual planks were carried a distance of about 30 ft by laborers and placed in position. One laborer inserted end-connecting rods between the planks at the end joints. Although the placement of the mat was not timed, the average placing time for the AM2 is approximately 225 sq ft per man-hour.

14. The entire test section was surfaced with WACO three-piece AM2. The planks were placed with the long axis perpendicular to the direction of traffic, as shown in plate 1. The surfaced test section was approximately 24 ft wide. The first run of mat consisted of two full planks placed end to end, and the second run consisted of one full plank in the center with half planks on each end; this alternating pattern was continued throughout the test section of 75 runs, or approximately 150 ft, and provided a staggered-joint configuration as shown in plate 1. Items 1, 2,

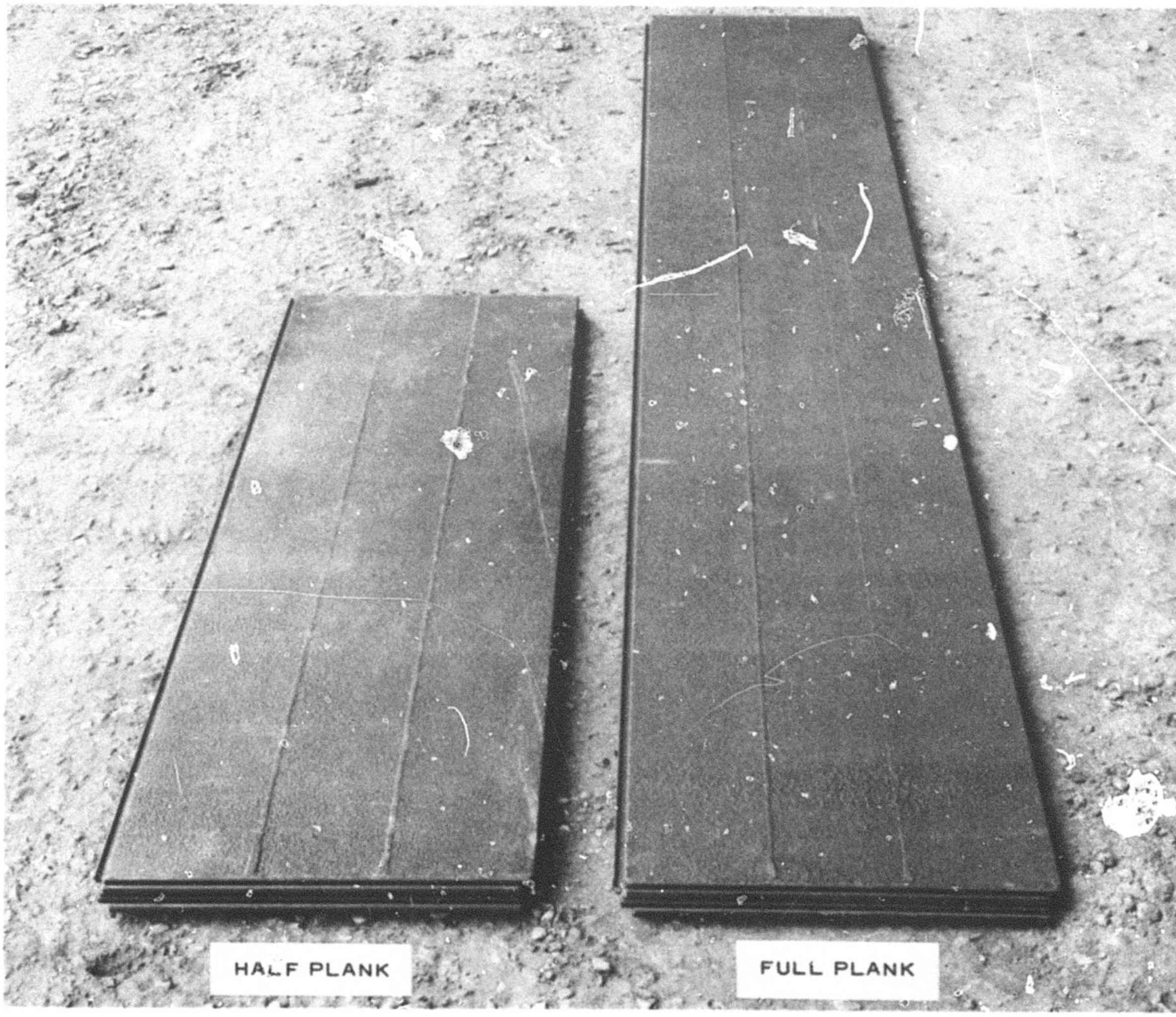

Fig. 1. WACO three-piece AM2 mat

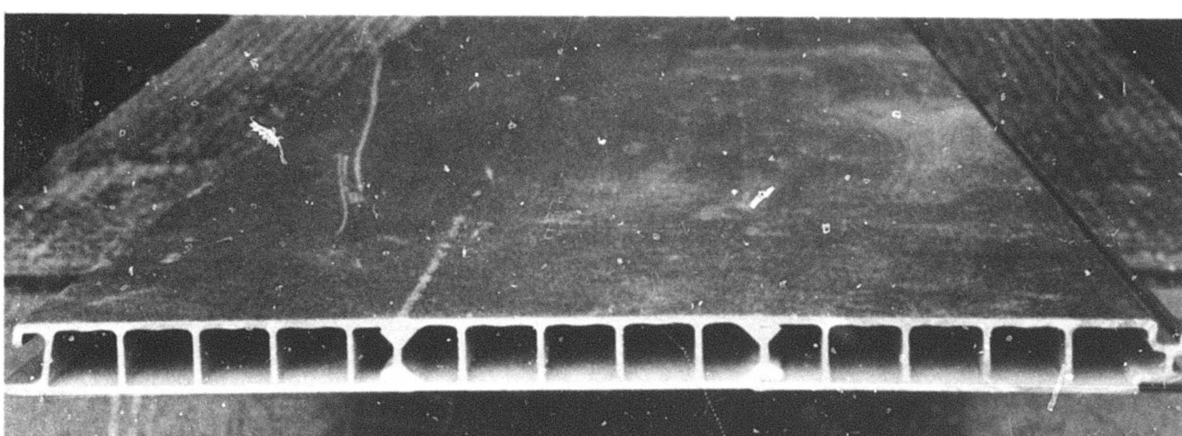

Fig. 2. Cut section of three-piece AM2 mat

and 3 were each surfaced with 20 runs of mat. The individual extrusions making up each plank are referred to in this report as north, south, or center as oriented in the test section (see plate 1).

Test Load Cart

15. A specially designed single-wheel test cart (fig. 3) loaded to 27,000 lb was used in the traffic tests. It was equipped with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The load cart was equipped with the specified 30-7.7, 18-ply rating tire inflated to 400 psi. For the 27,000-lb wheel load, the tire had a contact area of about 82 sq in. and an average contact pressure of 330 psi.

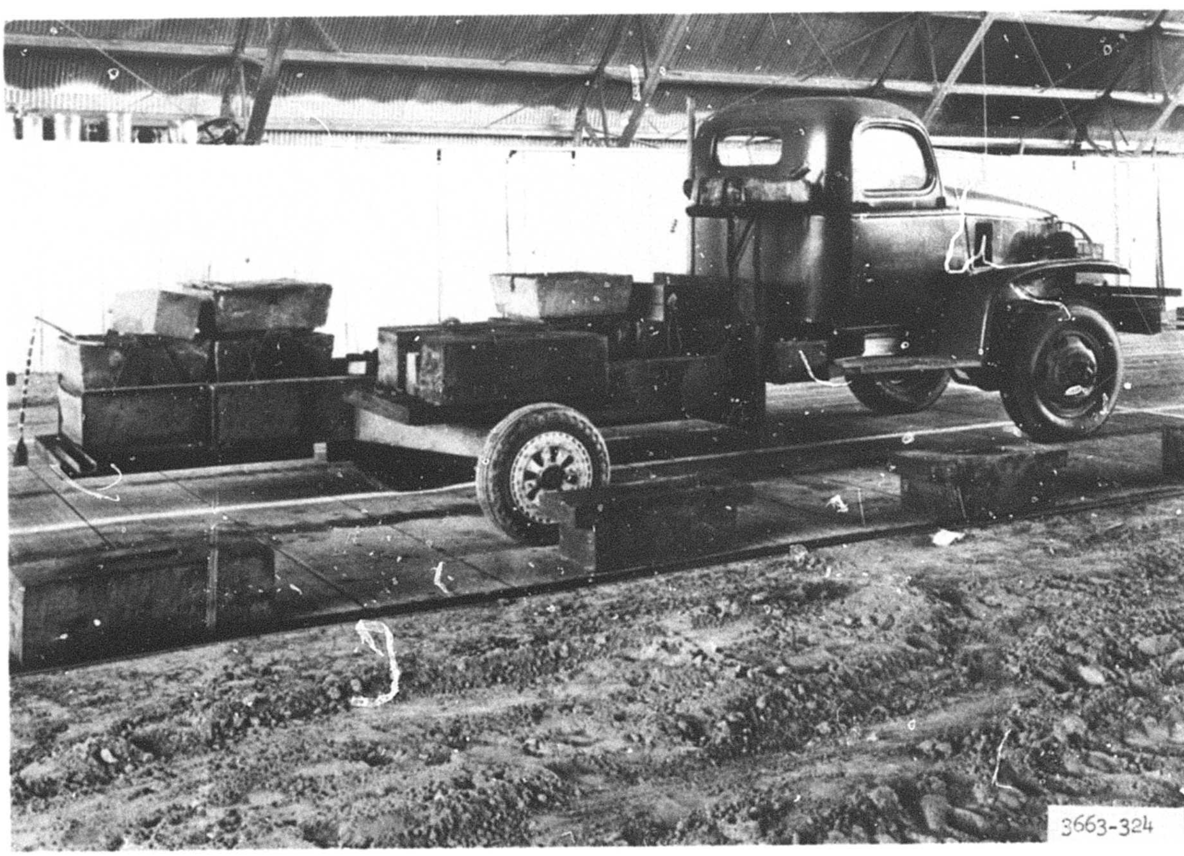

Fig. 3. Test load cart

prior to traffic and at failure or the end of traffic in each test item. These tests were made at depths of 0, 6, and 12 in., and at least three tests were made at each depth. The data obtained from the tests are summarized in table 1. The values listed in table 1 corresponding to the various depths are averages of the values measured at each particular depth.

19. Visual observations of the behavior of the test items and other pertinent data were recorded throughout the traffic test period. These observations and data were supplemented by photographs. Level readings were taken on the mat prior to and at intervals during traffic to show the development of permanent mat deformation and deflection of the mat under the wheel load.

Failure Criteria

20. The criteria for mat failure were the same as those used in previous tests of this series, and are based primarily on mat breakage. It was assumed that a certain amount of maintenance would be performed in the field during actual usage and that minor metal or weld breaks could be easily repaired. However, in this test when an end connector broke off or a mat core collapsed, the mat plank was considered failed beyond repair, and the plank was replaced. It is considered feasible to replace up to 10 percent of the AM2 planks with new mat during the design service life of a runway; however, replacement in excess of 10 percent of the planks is not considered practical. Therefore, in this test, it was assumed that in each test item up to 10 percent of the mat planks could be replaced and when an additional 10 percent of the planks had failed (a total of 20 percent failed), the entire item was considered failed.

Behavior of Mat Under Uniform-Coverage Traffic, Test Lane 1

Visual observations

21. Item 1. A general view of item 1 prior to traffic is shown in photograph 1. After four coverages, it was noticed that the ends of the

PART III: TESTS AND RESULTS

Traffic Tests

Uniform-coverage traffic

16. As stated earlier, the objective of uniform-coverage traffic was to simulate a main landing-gear wheel traversing a mat surface during landings and normal takeoffs. Therefore, a 10-ft-wide traffic lane was laid out down the center of the test section, as shown in plate 1. Lead weights were used along the edges of mat for anchoring and to simulate the weight of the wider section of mat that would normally be laid on a runway (photograph 1). Traffic was applied by driving the load cart forward and then backward over the length of the test section, then shifting the path of the cart laterally about 7.3 in. (one tire-print width) and applying another two passes. This procedure resulted in two complete coverages of traffic on the test lane each time the load cart was maneuvered from one side of the lane to the other. Traffic was applied until failure of the mat in each test item had occurred or until 188 coverages had been completed, whichever occurred first.

Single-line traffic

17. In aircraft launching operations employing a CE-type catapult, the aircraft is always launched from the same position on the runway, and the wheels of each aircraft follow essentially the same path on every takeoff. To simulate this type of loading, traffic was applied in a single path on a line approximately 3 ft outside the uniform-coverage traffic lane and 4 ft from the east edge of the mat as shown in plate 1. Traffic was applied on each item to failure or until 1600 passes had been completed, whichever occurred first. For this traffic, the weights along the east edge of the mat were removed because NAEC desired that the mat edge not be restrained during traffic.

Soil Tests and Miscellaneous Observations

18. Water content, density, and in-place CBR tests were conducted

overlapping end-joint connectors were slightly curled due to the planks flexing under traffic (photograph 2). At 20 coverages, small cracks appeared in the end-connector welds of planks 25 and 26 (the end-connector weld joins the end connectors with the extruded portion of the planks). Generally, the item was in excellent condition. After 40 coverages, there were six end-joint weld cracks, three on overlapping and three on underlapping connectors at the ends of abutting planks. The first mat failure occurred at 100 coverages when the end connector separated from the extrusion on plank 29 due to an end-connector weld break on the underside of the plank (photograph 3). Since the end connectors of planks 29 and 30 were locked together, the top skin of plank 29 was torn loose from the longitudinal ribs as the plank deflected under the test load.* Also after 100 coverages it was noticed that there was apparent core damage to four planks in an area on each plank opposite the joint of the preceding run (photograph 5). At this time there were 15 end-connector weld cracks varying in length from 1/2 to 13 in. At 122 coverages, planks 13, 25, and 26 were considered failed owing to an end-connector weld failure such as that shown in photograph 6. Plank 28 also was considered failed because of core damage in the extrusion on the north side of the plank. At 136 coverages, plank 22 failed when the top lip of the underlapping end connector sheared (photograph 7), bringing the number of failed planks to six. The entire section, therefore, was considered failed at 136 coverages. A general view of item 1 at failure is shown in photograph 8. At failure, in addition to the failed planks, there were 13 end-connector weld cracks, 7 apparent core damage areas, and 4 end curls broken off. The weld cracks averaged approximately 5 in. in length. As shown in photograph 8, a slight amount of lateral shifting of the planks

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* Obviously, it is impossible to detect a crack in a weld in the bottom of a plank during trafficking until some type of breakage appears on the top side of the mat. In the case of plank 29, the top end-connector weld was stronger than the skin since the failure was evidenced by a skin tear. In other cases it is quite possible that what is detected as a weld crack on top of the end connector is a result of a prior failure in the weld directly below the crack. In any case, complete separation of the end connector from the extrusion must be preceded by a failure on both the top and bottom of the plank (photograph 4).

had occurred during trafficking. It was noticed during the latter part of the test that the mat deflected considerably as the test load vehicle traversed the item.

22. Item 2. A general view of item 2 prior to traffic is shown in photograph 9. After four coverages, a small crack had developed in the end-connector weld of plank 65, and after eight coverages, small cracks had occurred in the end-connector welds of two additional planks. At 20 coverages, the weld break in plank 65 had progressed almost entirely across the plank (photograph 10), but no new breaks had occurred in the item, which was in excellent condition. After 40 coverages of traffic, the end-connector weld of plank 65 sheared off completely and the plank was considered failed (see photograph 11). At 100 coverages of traffic, plank 74 failed owing to end-connector weld failure. At this time, there were 10 weld breaks (in addition to the two failures) ranging in length from 1/2 to 18 in. Generally the item was in good condition. At 122 coverages, plank 77 failed because of end-connector weld failure, and plank 78 failed when the upper lip on the underlapping end connector sheared. Also, plank 80, which was adjacent to planks 77 and 78, failed at this time owing to core breakage in a localized area opposite the joint of planks 77 and 78. Traffic was continued to 174 coverages, at which time plank 45 failed through end-connector weld failure. This brought the total number of failed planks to six, and item 2 was considered failed. No new weld cracks had occurred from 100 to 174 coverages. A general view of item 2 at failure is shown in photograph 12. The end-connector weld breaks averaged approximately 6 in. in length at failure. As can be seen in photograph 12, some lateral shifting of the planks had occurred during traffic.

23. Item 3. A general view of item 3 prior to traffic is shown in photograph 13. The first mat breakage occurred at four coverages when a small hairline crack appeared in the end-connector weld of plank 98. At 20 coverages, there were four small weld cracks, and the item was in excellent condition. At 40 coverages, the weld cracks in plank 98 had progressed to 3 in., and plank 106 had two weld cracks, each about 2-1/2 in. long. Traffic was continued to 154 coverages, at which time

planks 98, 102, and 106 failed from end-connector weld failure. At 188 coverages, traffic was stopped with the item in serviceable condition (photograph 14). At 188 coverages, there were seven end-connector weld cracks which averaged 9 in. in length.

24. Item 4. A general view of item 4 prior to traffic is shown in photograph 15. The item withstood 188 coverages of traffic with only one break, an end-connector weld break in plank 122. The crack appeared in the weld at eight coverages and was approximately 1/2 in. in length. When traffic was stopped at 188 coverages, the crack had progressed to 2 in. There were no other breaks in the item, which was in excellent condition (photograph 16). It was noticed during the traffic test that the mat deflected considerably under the test load vehicle. The deflection increased as the test progressed and the sand subgrade consolidated under the mat.

Permanent deformation

25. Plots showing permanent mat deformation as determined from level readings taken prior to and at various levels of traffic coverage are shown in plate 3. These data indicate that the greatest deformation, about 0.9 in., occurred in item 4 after 188 coverages of traffic. Since this item had a loose sand subgrade, a large amount of consolidation resulting in mat deformation could be expected. Of the three items with a clay subgrade, the maximum deformation measured was about 0.6 in. in item 1 after 136 coverages of traffic. The maximum deformations measured in items 2 and 3 at end of traffic were 0.4 and 0.3 in., respectively. A plot of deformation along the center line of the traffic lane is shown in plate 4.

Elastic deflection

26. Elastic deflections of the mat surface prior to and after traffic are shown in plate 5. These plots indicate the elastic deflection, or rebound, of the mat as the wheel load moved over the surface. Two plots are shown for each item as follows: the data for the first plot were taken with the load wheel centered on the joint of the planks, and the data for the second plot were taken with the wheel centered on the

midpoint of a plank. In both cases, the load wheel was positioned in the center of the traffic lane.

27. The plots indicate that in items 1, 2, and 3, there was little change in elastic deflection over the trafficking period. The largest increase, 0.3 in., was observed in item 1. The maximum deflection in items 1, 2, and 3 at the end of traffic was 1.0, 0.7, and 0.6 in., respectively. In item 4, the mat deflection increased from 0.8 in. before traffic to 2.0 in. after traffic. This increase is attributed to consolidation of the sand subgrade and subsequent bridging of the mat. In all four items, the maximum deflection occurred under the plank joints.

Behavior of Mat Under Single-Line Traffic, Test Lane 2

Visual observations

28. Item 1. When the weights were removed from the east edge of the mat, the mat ends sprang upward 2 to 3 in. as a result of deformation in test lane 1. Therefore, the mat was not in continuous contact with the subgrade. A general view of item 1 prior to traffic is shown in photograph 17. The effects of traffic were first noticed at 740 passes when a slight amount of dishing was observed in the individual extrusions of several planks (photograph 18). Dishing measurements were made in each of the three extrusions of each plank, but generally dishing was not noticeable until it progressed to about 3/16 in. deep. At about 3/8 in. dishing depth, an extrusion was considered to have a core failure which generally was indicated by an accompanying skin or weld break. The first mat break was noticed at 806 passes in plank 5. There was a 1/4-in.-deep dish in the extrusion on the south side of the plank, and the adjacent longitudinal weld had a 2-1/2-in. crack. At 1000 passes, a skin tear appeared in plank 5 adjacent to the longitudinal weld crack, as shown in photograph 19. In addition, on plank 3 a 5-in.-long crack had developed in the longitudinal weld on the south side of the plank, and there was a dish approximately 1/4 in. deep in the south extrusion. At this time, three additional planks with areas of apparent core damage were noted. The item was in good condition, generally, although there had been some lateral

shifting of the planks during trafficking (photograph 20). At 1222 passes, planks 19 and 37 failed from breakage in the core of the extrusion on the south side of the plank and subsequent tearing of the aluminum skin near the longitudinal weld. After 1320 passes, planks 5, 9, 25, and 33 failed from core breakage and subsequent skin tear. Dishing in the failed extrusions of the four planks averaged 3/8 in. in depth, and the skin breaks averaged about 5 in. in length. All failed extrusions were on the south side of the plank. This brought to six the number of planks failed in item 1, and the item was considered failed (photograph 21). In addition to the failed planks, there were six planks with areas of apparent core damage (severe dishing), three of which had longitudinal weld cracks. Upon removal of the mat at the end of traffic, longitudinal weld cracks were found on the underside of eight planks. Most of the breaks on the underside of the planks occurred in areas directly below a failed or damaged core.

29. Item 2. A general view of item 2 prior to traffic is shown in photograph 22. This item withstood trafficking without significant visible effects until 1320 passes, at which time it was observed that eight planks had slightly dished extrusions. At 1520 passes, a large crack had occurred in the longitudinal weld on the south side of plank 61 and a skin tear at the same relative position on plank 77 (photograph 23). Both breaks appeared suddenly and as a result of core damage. After 1600 passes, traffic was stopped. At this time, in addition to planks 61 and 77, there were 14 areas of apparent core damage in the item. In about half of the damaged planks failure appeared to be imminent, and the item was generally in poor condition (photograph 24).

30. Item 3. Item 3 withstood 1600 passes of traffic with no apparent mat damage. Views of item 3 before and after the traffic test are shown in photographs 25 and 26, respectively.

31. Item 4. Item 4 withstood 1600 passes of traffic with only one area of apparent core damage and no exterior mat breakage. When traffic was stopped, plank 147 had a 1/4-in.-deep dish in the extrusion on the north side of the plank. Views of item 4 before and after traffic are shown in photographs 27 and 28, respectively.

Permanent deformation

32. Plots showing permanent mat deformation as determined from level readings taken prior to and at the end of traffic are shown in plate 6. The plots indicate that the maximum deformation of 0.9 in. occurred in item 4 at 1600 passes. As with the uniform-coverage traffic, large deformations could be expected in this item since the loose sand subgrade compacted under traffic. In item 1, the maximum deformation at failure measured 0.4 in. Since the traffic path was 4 ft from the edge of the mat and the mat edge was unrestrained during the single-line traffic test, the planks tended to bend about an axis coincident with the traffic path causing the mat edge to protrude upward progressively as traffic was applied. This was more apparent in items 1 and 2 than in items 3 and 4 (plate 6). A profile of mat deformation along the traffic path is shown in plate 7.

Elastic deflection

33. Elastic deflections of the mat surface prior to and after traffic are shown in plate 8. These data indicate that in item 1 there was considerable deflection both before and after traffic, measuring 1.1 and 1.9 in., respectively. In items 2, 3, and 4, elastic mat deflection after traffic was less than the deflection before traffic. In item 2, the deflection before traffic measured 1.4 in. and after traffic, 1.3 in. In item 3, the deflection before and after traffic measured 0.9 and 0.7 in., respectively. In item 4, the maximum deflection before traffic measured 2.4 in. and after traffic, 0.9 in. The high initial deflection was due to the removal of the restraining weight from the edge of the mat after uniform-coverage traffic. Removal of the weight caused the mat edges to spring upward as previously discussed (paragraph 28).

PART IV: SUMMARY AND ANALYSIS OF TEST RESULTS

Uniform-Coverage Traffic

Test results

34. A summary of the test results for lane 1 is shown in table 2. Included in the table are the rated subgrade CBR, mat breakage and deflection data taken at various stages of traffic, and the performance rating of the various test items based on the failure criteria described in paragraph 20. The rated CBR for the clay subgrade of items 1, 2, and 3 is based on the numerical average of the CBR values measured at 0-, 6-, and 12-in. depths prior to and at the end of the traffic period (table 1). For the sand subgrade in item 4, the initial CBR prior to traffic was quite low due to the looseness of the sand. However, as traffic was applied, the sand densified, and the subgrade strength increased considerably to a CBR of about 38. Due to the large change in strength of the sand during the traffic period, no specific rated value is assigned; instead the CBR values as determined before and after trafficking are shown in table 2.

35. As can be noted in table 2, item 1 failed at 136 coverages, and item 2 at 174 coverages, the lower strength item failing first. Both items 3 and 4 withstood 188 coverages of traffic without failure. Although item 2 failed 38 coverages after item 1, there was a similarity in performance of the two items. In both, there was a multiplank failure at 122 coverages which brought the total number of planks failed in each item at that time to five. In each item, there were three overlapping, end-connector weld failures, one underlapping, end-connector weld failure, one core failure, and one end-connector lip failure. At failure, however, there were almost twice as many mat breaks in item 1 as in item 2 (including 6 failed panels in each item).

36. Item 3 performed satisfactorily through 188 coverages, sustaining only 10 breaks (3 planks were considered failed). All failures in this item were end-connector weld failures.

37. Item 4 performed satisfactorily through 188 coverages, sustaining

only one break. As the traffic test proceeded and the sand subgrade consolidated, the elastic deflection of the mat increased considerably due to bridging of the mat over the subgrade. However, there was no evidence that the high deflection was detrimental to the mat.

38. All core failures in lane 1 were located in an area of the plank adjacent to the joint of the preceding run and were caused by joint failure and subsequent deflection which resulted in the core's sustaining the impact of the load wheel. As can be seen in photograph 29, the core failure was limited to the extrusion nearest the joint. It should be noted that all failures and breaks which occurred during uniform-coverage traffic were located at or adjacent to an end joint.

Service life

39. A plot of CBR versus coverages for the uniform-coverage traffic is shown in plate 9. The points plotted are the rated CBR values listed in table 2 for the clay subgrades and the corresponding number of coverages at the end of traffic. From previous tests on landing mats, it has been established that the CBR-coverage relation for landing mat is essentially a straight line when plotted to a log-log scale. Therefore, the linear projection through the two failure points on plate 9 indicates the CBR required to support a 27,000-lb single-wheel load with 400-psi tire pressure for various coverage levels. The indicated CBR required to support 188 coverages of traffic is approximately 6.8.

40. Using the technique described in WES Miscellaneous Paper No. 4-615,* a CBR design curve was developed for the WACO three-piece AM2. This curve is shown in plate 10a. The design curve was computed for 188 coverages of a 27,000-lb single-wheel load with a tire pressure of 400 psi. The lower curve is the standard flexible pavement design curve.

Single-Line Traffic

Test results

41. A summary of the test results for lane 2 is shown in table 3.

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* Op. cit.

Included in the table are the rated subgrade CBR, mat breakage and deflection data taken at various stages of traffic, and the performance rating of each test item based on the failure criteria described earlier (paragraph 20). Computations of the rated CBR for items 1, 2, and 3 were based on the method discussed in paragraph 34. Also, as noted earlier, a range of strength values is given for the sand subgrade of item 4 in lieu of a rated CBR.

42. Item 1 failed at 1320 passes with six planks failed and six additional areas of apparent core damage. In item 2, there were 16 areas of apparent core damage when traffic was stopped at 1600 passes. Core damage varied from slight to severe, with almost half of the breaks incipient failures. Since the overall condition of the item was rated poor when traffic was stopped, item 2 was considered to have failed at 1600 passes for purposes of analysis. No damage was observed in item 3, and there was one core break in item 4 when traffic was stopped at the end of 1600 passes.

43. All mat breakage was the result of initial core failure in one or more of the individual extrusions making up a plank, particularly the extrusions with the side connectors (photograph 30). The six core failures in item 1 occurred in extrusions on the south side of the plank, which were the extrusions with the male side connectors. Of the 29 areas of apparent core damage in the test lane, 16 occurred in extrusions having the male side connector, 7 were located in extrusions having the female side connector, and 6 occurred in the center extrusions. Of the planks that were considered failed during the test, the metal skin on top of each plank generally failed before the adjacent longitudinal weld (photograph 23). In item 1, there were six skin tears at failure versus three longitudinal weld cracks on top of the mat. However, longitudinal weld cracks were found on the bottom of eight planks when the mat was removed at the end of traffic. There was no indication of the period during which these cracks occurred. Since the single-path traffic lane was 2 ft from the closest line of end joints, obviously no end connectors were located in the traffic lane and, therefore, no end-connector failures occurred.

Service life

44. A plot of CBR versus passes for the single-line traffic test is shown in plate 11. This plot is similar to the CBR-coverages plot shown in plate 9, the development of which was described in paragraph 39. In plate 11, the rated CBR's for the clay items from table 2 are plotted against the number of passes completed when traffic was stopped. As noted in paragraph 42, item 2 was considered to be failed at 1600 passes for analysis purposes and is plotted as such in plate 11. The data in plate 11, therefore, indicate that a CBR of approximately 5.7 is required to support 1600 passes of a 27,000-lb single-wheel load with 400-psi tire-inflation pressure.

45. Using the technique described in Miscellaneous Paper No. 4-615,* a CBR design curve was developed for the WACO three-piece AM2 to sustain 1600 passes of a 27,000-lb single-wheel load with 400-psi tire pressure. This curve is shown in plate 10b with the standard flexible pavement CBR design curve.

Discussion

46. From plates 9 and 11, it can be seen that under the three-piece AM2 a slightly higher subgrade strength is required to support 188 coverages of traffic distributed uniformly over a 10-ft-wide lane than is required to support 1600 passes of single-line traffic. However, most of the mat failures in the uniform-coverage traffic test lane were due to end-connector failure, whereas since there were no end joints in the single-path traffic lanes, the only mat breaks occurred because of core damage. Therefore, the service life of the mat under single-line traffic applied in close proximity to the end joints might be considerably different from that indicated by these tests.

47. It should be noted that the mat performance was not affected to any material extent by the three-piece weld configuration since no plank failures or severe breaks were attributed directly to longitudinal weld failure.

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* Op. cit.

PART V: CONCLUSIONS

48. Based on the data presented in this report, the following conclusions are drawn:

<u>a</u>. The WACO three-piece AM2 will sustain 1600 cycles (188 coverages) of aircraft operations with a 27,000-lb single-wheel load and 400-psi tire-inflation pressure when placed on a subgrade having a CBR of 6.8 or greater throughout the period of traffic.

<u>b</u>. The WACO three-piece AM2 will sustain 1600 passes of a 27,000-lb single-wheel load with a tire-inflation pressure of 400 psi in a single path located 2 ft or more from the mat end joints when placed on a subgrade having a CBR of 5.7 or greater throughout the period of traffic.

<u>c</u>. General behavior of the mat in these tests was not materially affected by the three-piece nature of the planks.

Table 1

Summary of CBR, Water-Content, and Dry-Density Data

Test Item	Subgrade Material	0 Coverages: Pit No.	Depth in.	CBR	Water Content %	Dry Dens. pcf	Failure or End of Traffic: Traffic Passes or Cov	Pit No.	Depth in.	CBR	Water Content %	Dry Dens. pcf
Test Lane 1												
1	Clay	1&2	0	2.8	28.1	92.6	136	9	0	2.9	29.1	93.9
			6	2.8	29.0	94.3			6	3.5	28.0	95.5
			12	3.3	28.5	92.5			12	4.0	27.2	94.9
2	Clay	3&4	0	5.3	24.0	97.5	174	10	0	8.0	22.9	101.7
			6	4.3	26.3	94.4			6	4.3	25.7	94.3
			12	5.8	26.5	96.6			12	5.7	27.2	98.4
3	Clay	5&6	0	8.0	22.9	99.2	188	11	0	13.0	20.9	103.4
			6	8.0	22.8	99.7			6	12.0	21.8	102.4
			12	12.0	22.0	101.0			12	12.0	21.0	101.5
4	Sand	7&8	0	4.1	7.2	102.3	188	12	0	36.0	6.7	109.4
			6	4.9	6.8	102.4			6	42.0	5.9	111.8
			12	4.8	6.8	101.5			12	35.0	5.9	109.7
Test Lane 2												
1	Clay	1&2	0	2.8	28.1	92.6	1320	13	0	3.7	27.4	94.6
			6	2.8	29.0	94.3			6	3.9	26.8	95.6
			12	3.3	28.5	92.5			12	4.8	26.1	94.7
2	Clay	3&4	0	5.3	24.0	97.5	1600	14	0	8.0	23.6	99.2
			6	4.3	26.3	94.4			6	5.4	24.9	97.3
			12	5.8	25.6	96.6			12	8.0	24.8	97.4
3	Clay	5&6	0	8.0	22.9	99.2	1600	15	0	13.0	21.8	101.9
			6	8.0	22.8	99.7			6	9.0	22.4	100.4
			12	12.0	22.0	101.0			12	8.0	22.0	100.1
4	Sand	7&8	0	4.1	7.2	102.3	1600	16	0	33.0	6.2	106.3
			6	4.9	6.8	102.4			6	37.0	6.9	109.3
			12	4.8	6.8	101.5			12	28.0	7.8	104.9

Table 2

Summary of Uniform-Coverage Traffic Test Results, Test Lane 1

Test Item	Rated Subgrade CBR	No. Planks Subjected to Traffic	Traffic Coverages	Mat Breaks: End-Joint Weld Break: Overlapping	Mat Breaks: End-Joint Weld Break: Underlapping	Mat Breaks: End-Joint Weld Sheared: Overlapping	Mat Breaks: End-Joint Weld Sheared: Underlapping	Mat Breaks: Apparent Core Damage	Mat Breaks: Core Failure	Mat Breaks: Upper Lip Sheared from End-Connector	Mat Breaks: End Curl Broken	Total No. Planks Failed	Max Mat Deflection in.	Rating of Item
1	3.2	30	0	--	--	--	--	--	--	--	--	--	0.7	--
			20	1	1	--	--	--	--	--	--	--	0.7	--
			40	3	3	--	--	--	--	--	--	--	0.7	--
			100	8	7	1	--	4	--	--	--	1	0.6	--
			136	9	8	3	1	8	1	1	4	6	1.0	Failed
2	5.6	30	0	--	--	--	--	--	--	--	--	--	0.6	--
			20	1	2	--	--	--	--	--	--	--	0.5	--
			40	1	3	1	--	--	--	--	--	1	0.5	--
			100	5	7	1	1	2	--	1	1	2	0.5	--
			174	5	7	3	1	2	1	1	2	6	0.7	Failed
3	11.0	30	0	--	--	--	--	--	--	--	--	--	0.5	--
			20	1	3	--	--	--	--	--	--	--	0.6	--
			40	2	3	--	--	--	--	--	--	--	0.6	--
			100	4	6	--	--	--	--	--	--	--	0.6	--
			188	4	6	--	3	--	--	--	--	3	0.6	Good
4	4.6-38*	23	0	--	1	--	--	--	--	--	--	--	0.8	--
			20	--	1	--	--	--	--	--	--	--	1.5	--
			40	--	1	--	--	--	--	--	--	--	1.8	--
			100	--	1	--	--	--	--	--	--	--	2.0	--
			188	--	1	--	--	--	--	--	--	--	2.0	Good

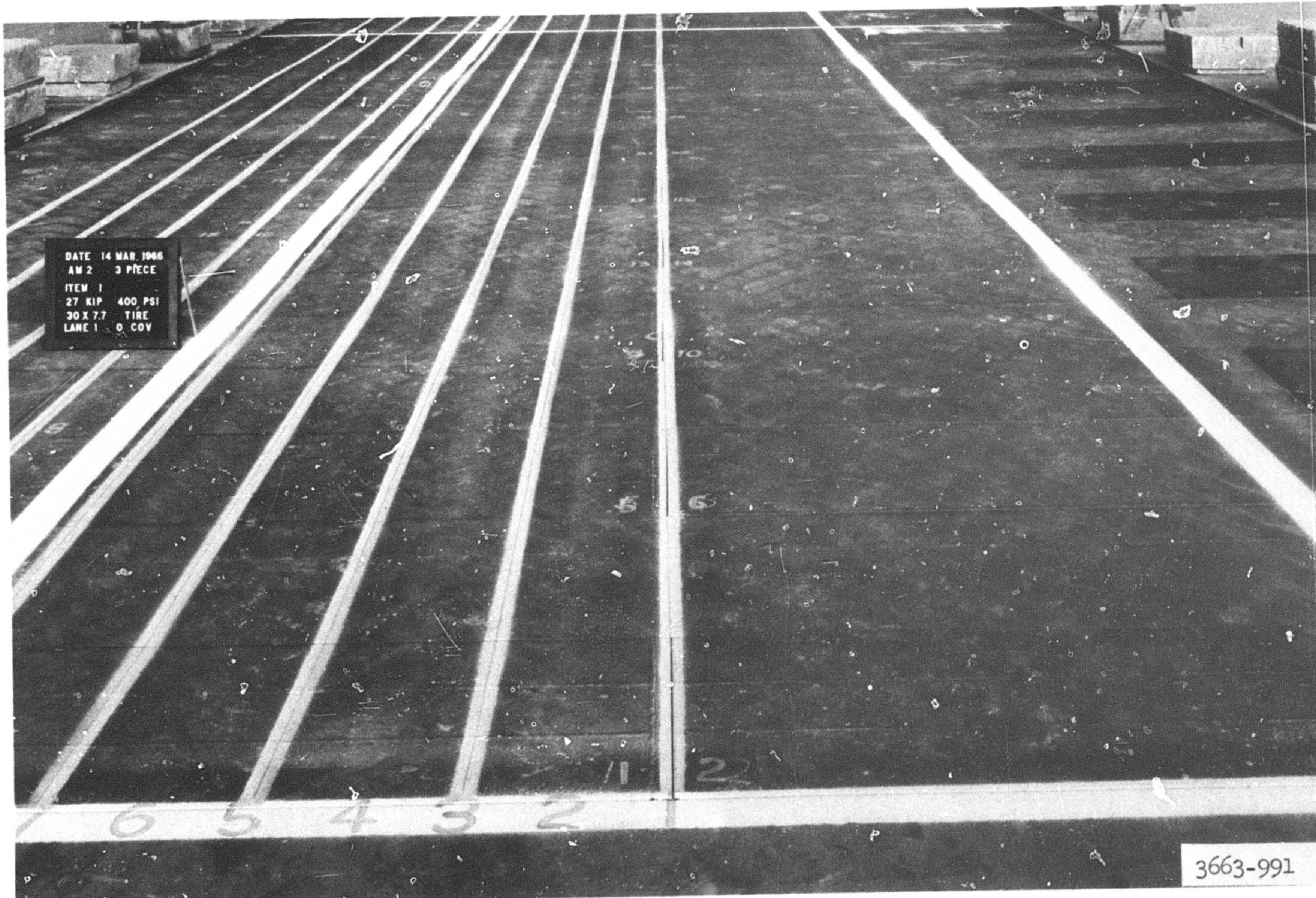
* CBR before and after traffic.

Table 3

Summary of Single-Line Traffic Test Results, Test Lane 2

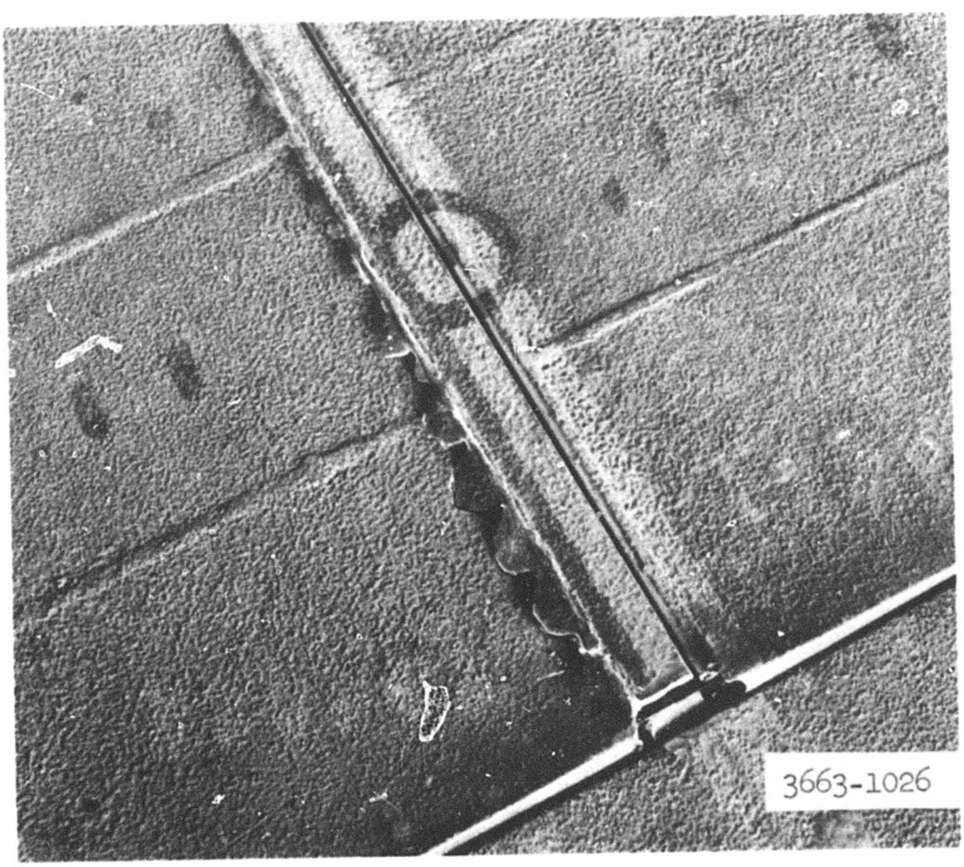
Test Item	Rated Sub-grade CBR	No. Planks Subjected to Traffic	Traffic Passes	Apparent Core Damage			Core Failure			Longitudinal Weld Crack		Longitudinal Weld Failure		Longitudinal Weld Crack on Bottom of Panel	Skin Tear on Top of Mat	Total No. Planks Failed	Max Mat Deflection in.	Rating of Item
				North Side	Center	South Side	North Side	Center	South Side	North Side	South Side	North Side	South Side					
1	3.3	20	0	--	--	--	--	--	--	--	--	--	--	--	--	--	1.1	--
			600	--	--	--	--	--	--	--	--	--	--	--	--	--	1.6	--
			1000	--	--	5	--	--	--	--	2	--	--	--	1	--	1.8	--
			1320	2	2	8	--	--	6	--	3	--	--	8	6	6	1.9	Failed
2	5.7	20	0	--	--	--	--	--	--	--	--	--	--	--	--	--	1.4	--
			600	--	--	--	--	--	--	--	--	--	--	--	--	--	0.8	--
			1000	--	--	--	--	--	--	--	--	--	--	--	--	--	1.1	--
			1600	4	4	8	--	--	--	--	1	--	--	1	1	--	1.3	Poor
3	9.0	20	0	--	--	--	--	--	--	--	--	--	--	--	--	--	0.9	--
			600	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	--
			1000	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	--
			1600	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	Good
4	4.6-33*	15	0	--	--	--	--	--	--	--	--	--	--	--	--	--	2.4	--
			600	--	--	--	--	--	--	--	--	--	--	--	--	--	0.8	--
			1000	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	--
			1600	1	--	--	--	--	--	--	--	--	--	--	--	--	0.9	Good

* CBR before and after traffic.

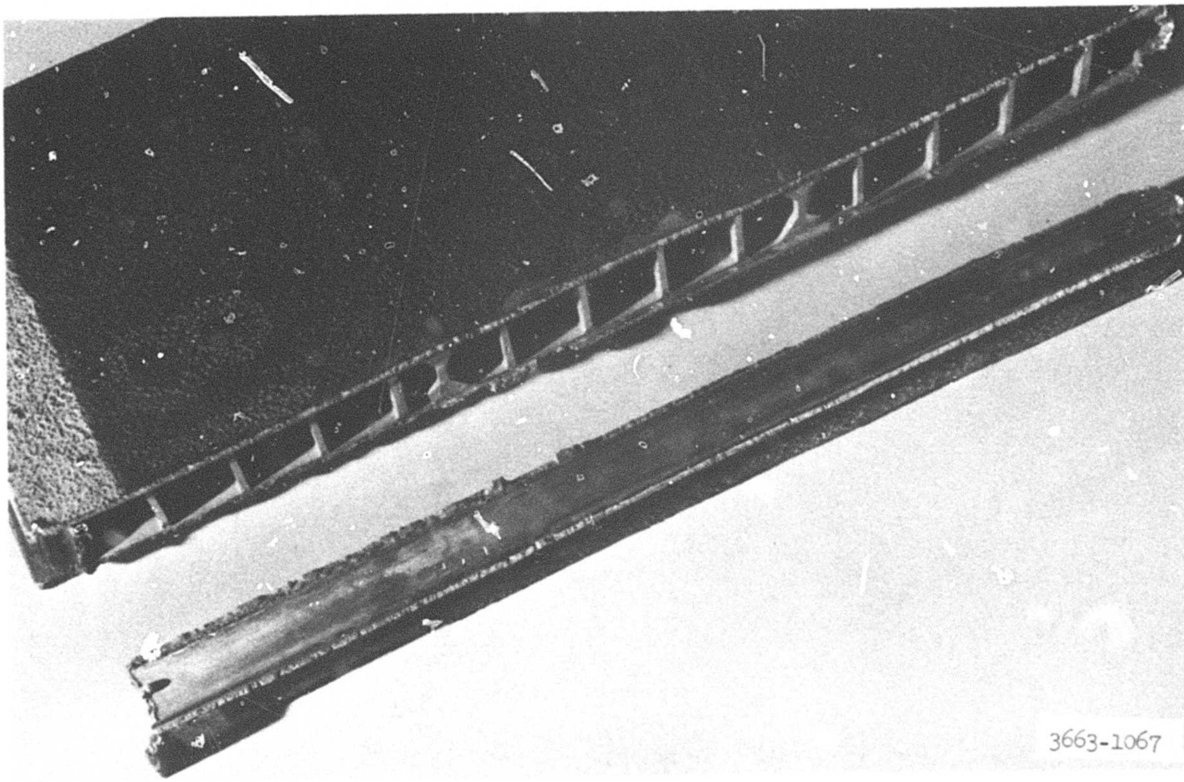


Photograph 1. Item 1, test lane 1, prior to traffic

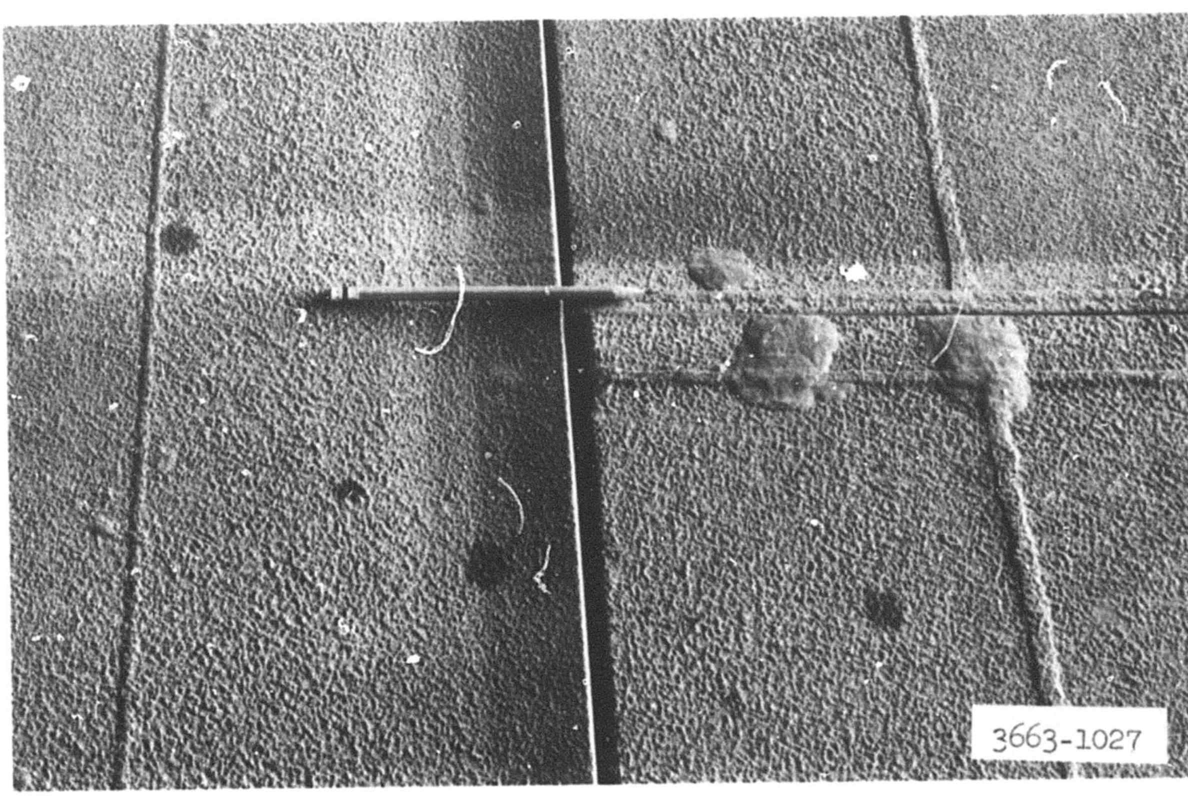
Photograph 2.
Overlapping
end-joint con-
nector curl,
item 1, lane 1



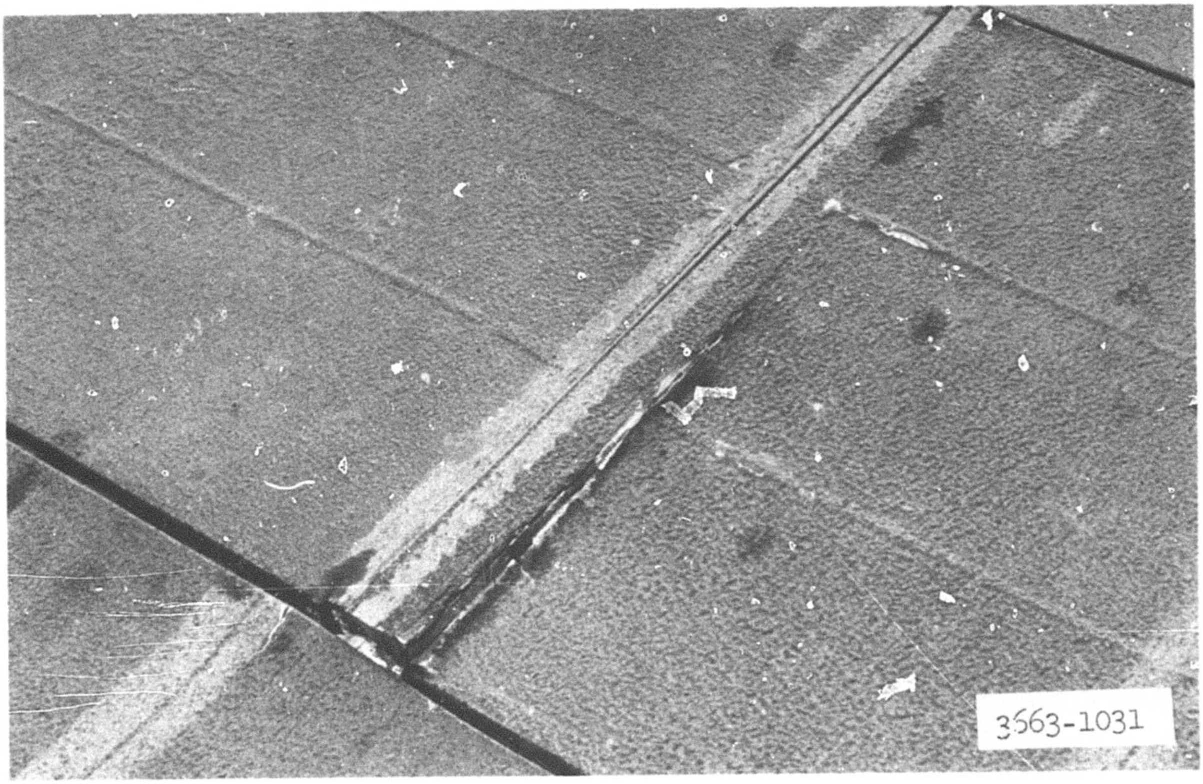
Photograph 3.
End-connector
weld failure
on underside
of mat re-
sulting in
top skin tear,
item 1, lane 1



Photograph 4. Complete separation of end connector and extrusion, item 1, lane 1



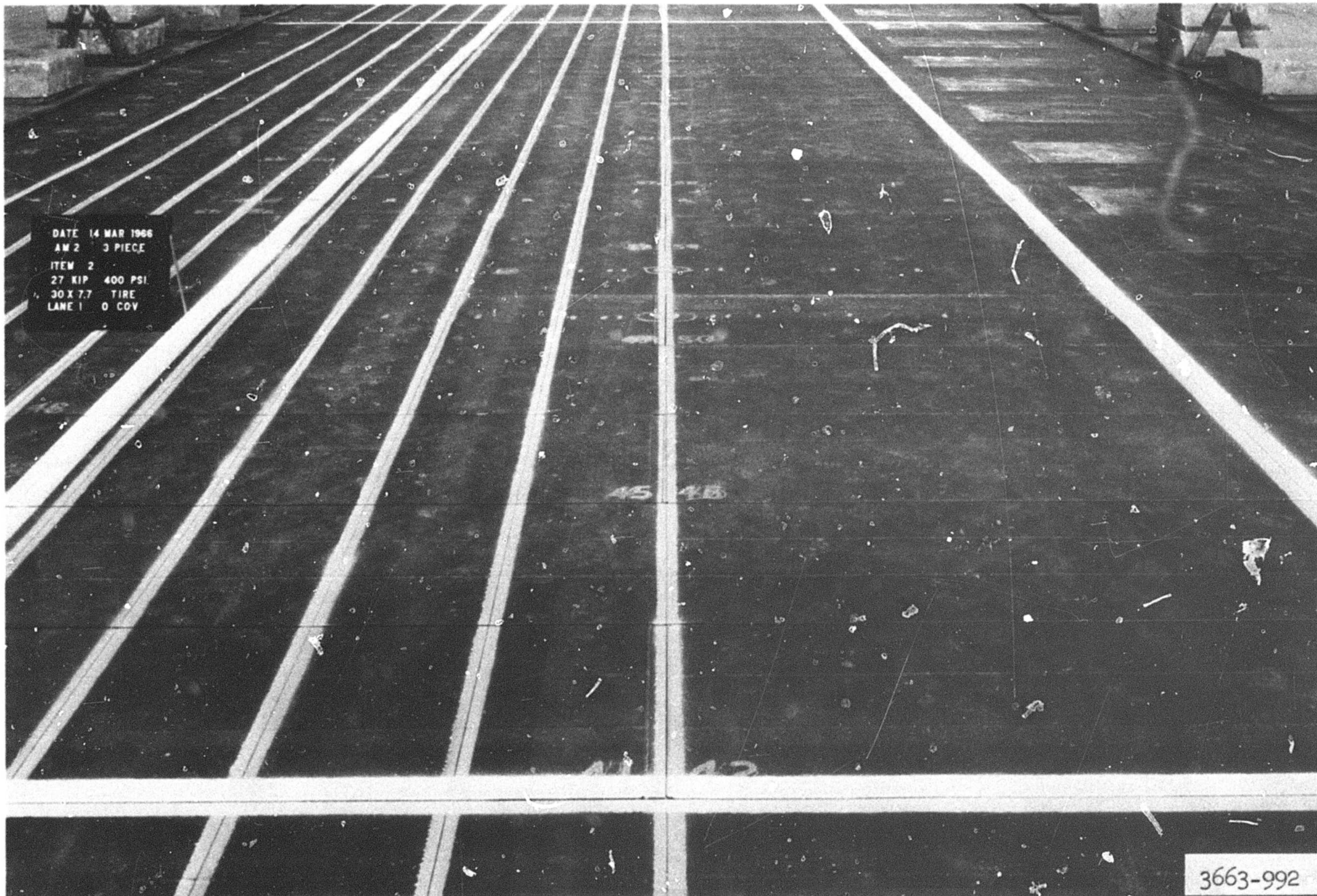
Photograph 5. Core damage opposite end joint, item 1, lane 1



Photograph 6. End joint weld failure, item 1, lane 1

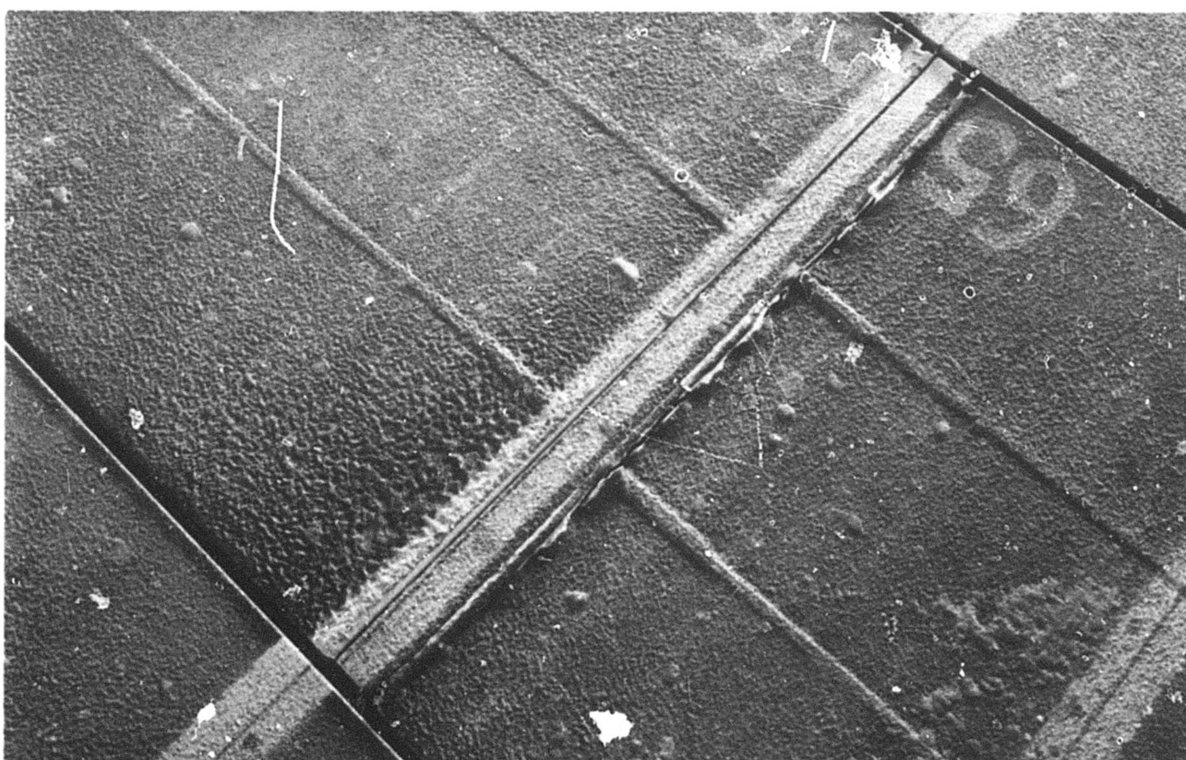
Photograph 7. Failure of top lip of underlapping end connector, item 1, lane 1

Photograph 8. Item 1, lane 1, at 136 coverages (failure)



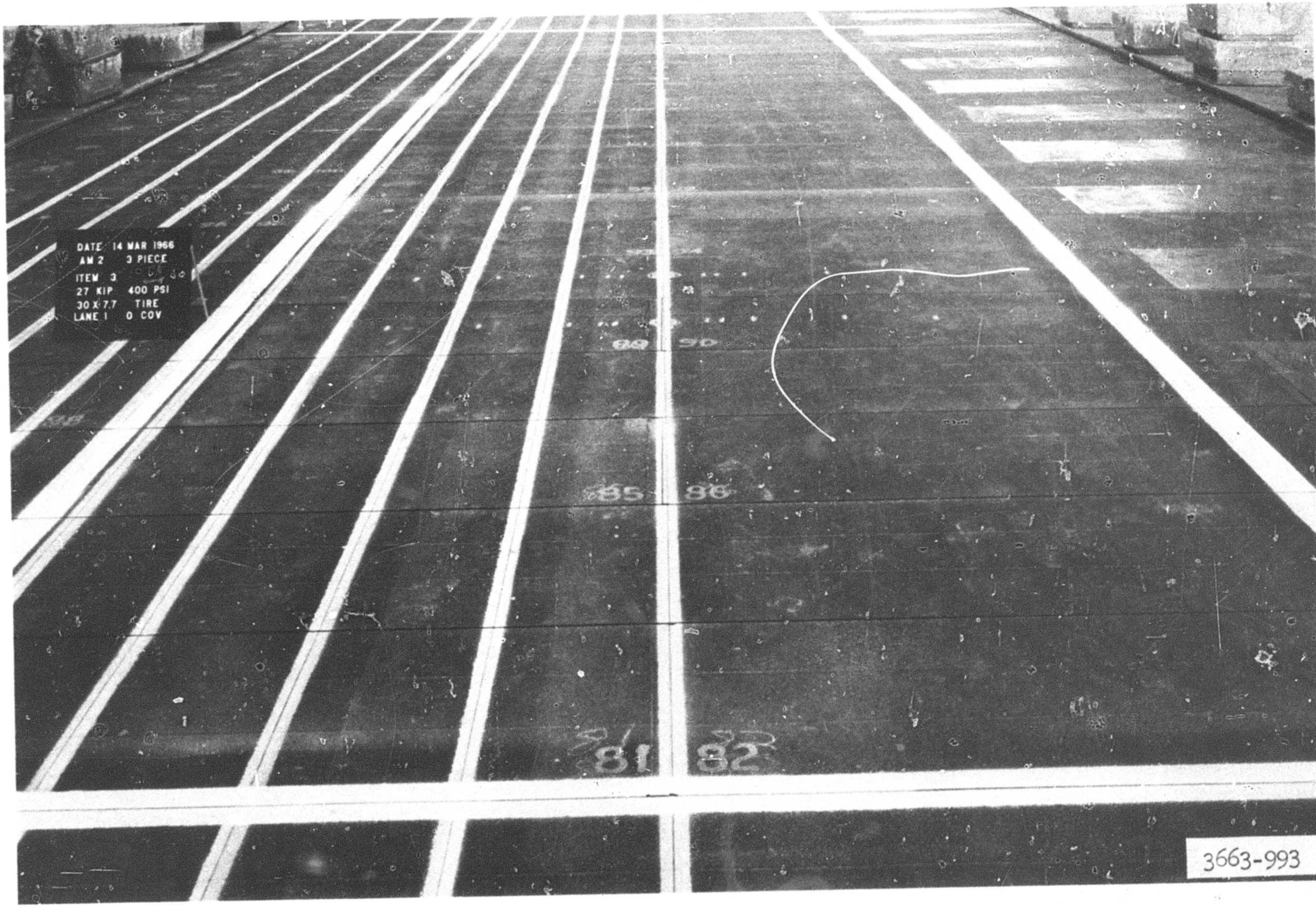
Photograph 9. General view of item 2, lane 1, prior to traffic

Photograph 10. End-connector weld crack in plank 65 after 20 coverages, item 2, lane 1

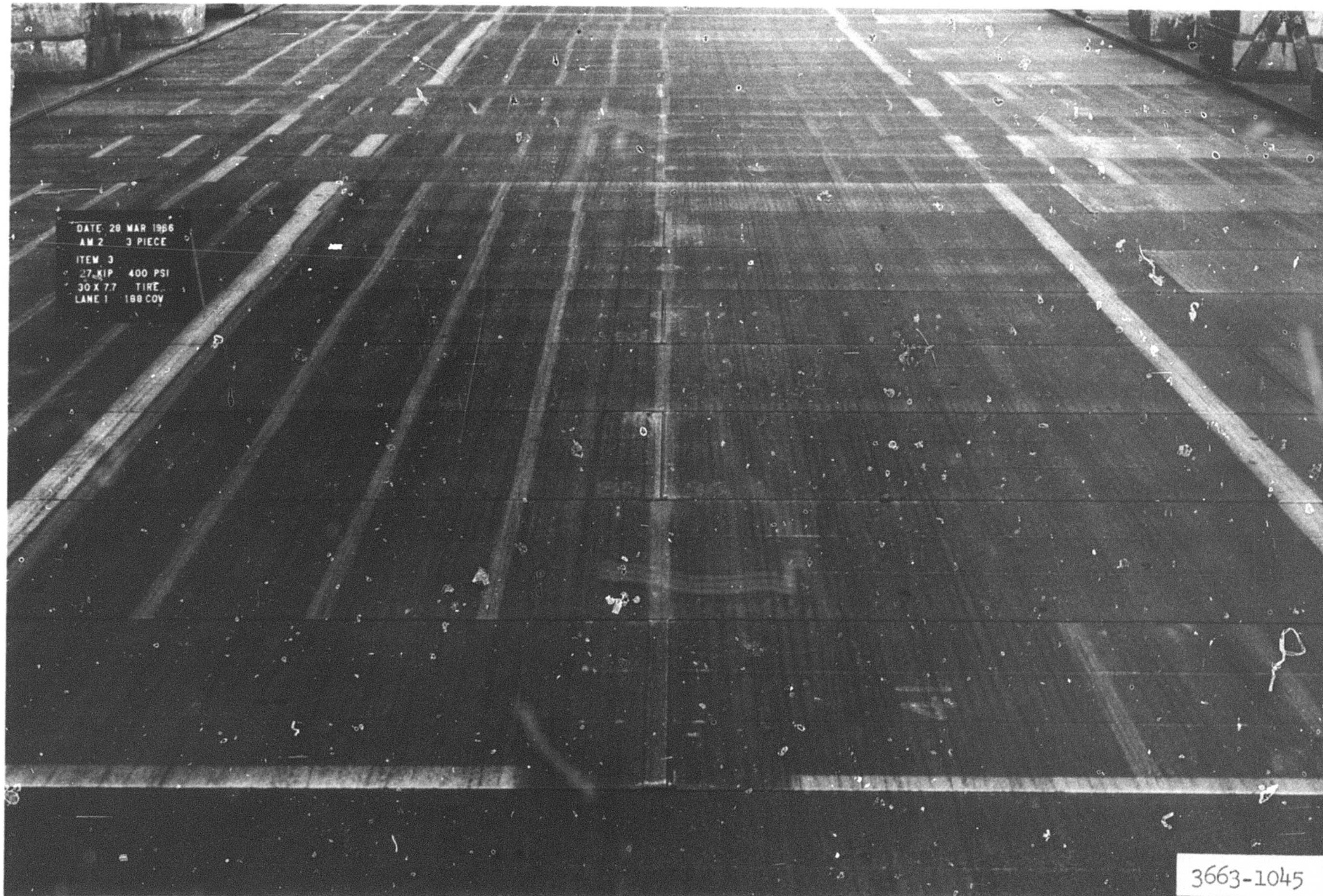


Photograph 11. Complete failure of end-connector weld in plank 65 after 40 coverages, item 2, lane 1

Photograph 12. General view of item 2, lane 1, at 174 coverages (failure)

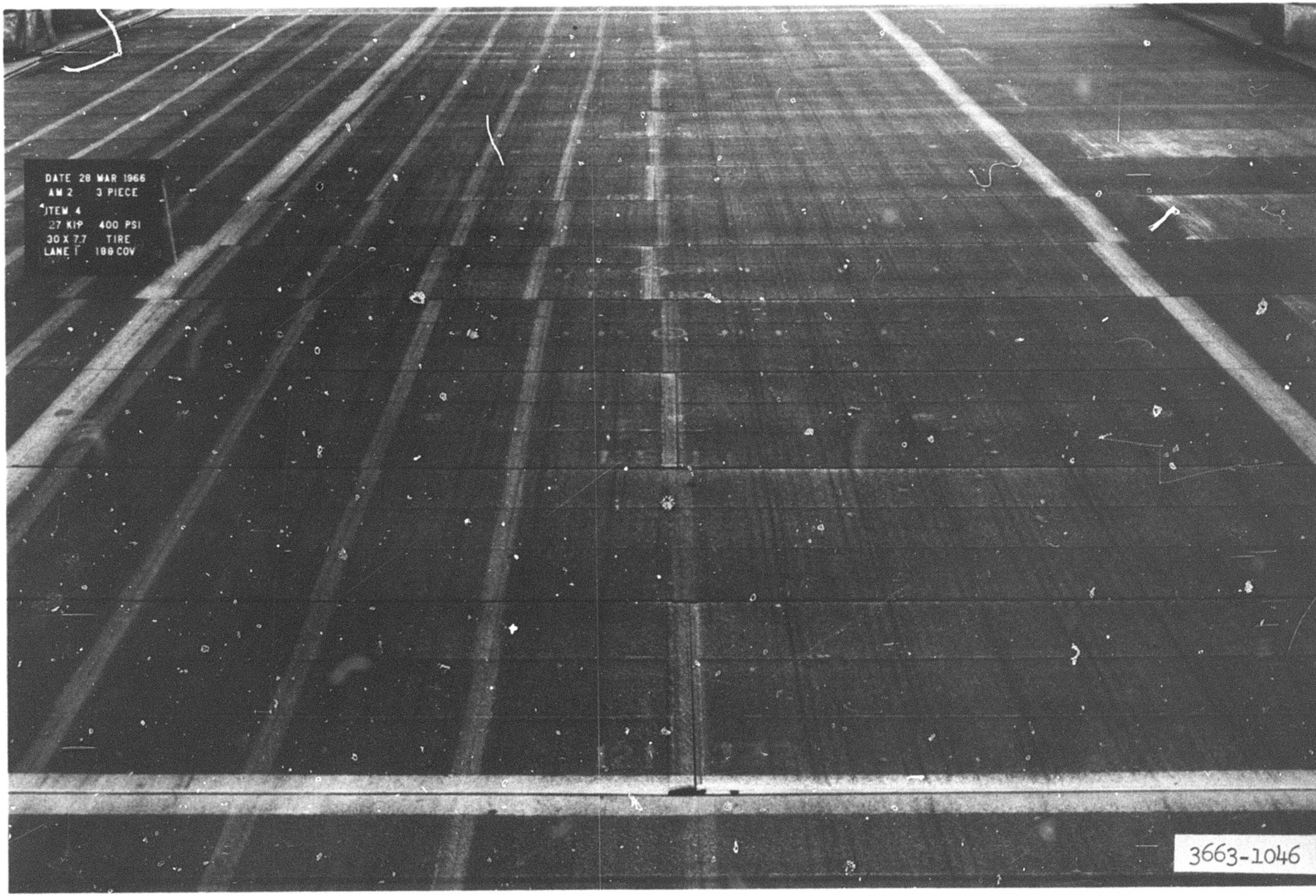


Photograph 13. General view of item 3, lane 1, prior to traffic



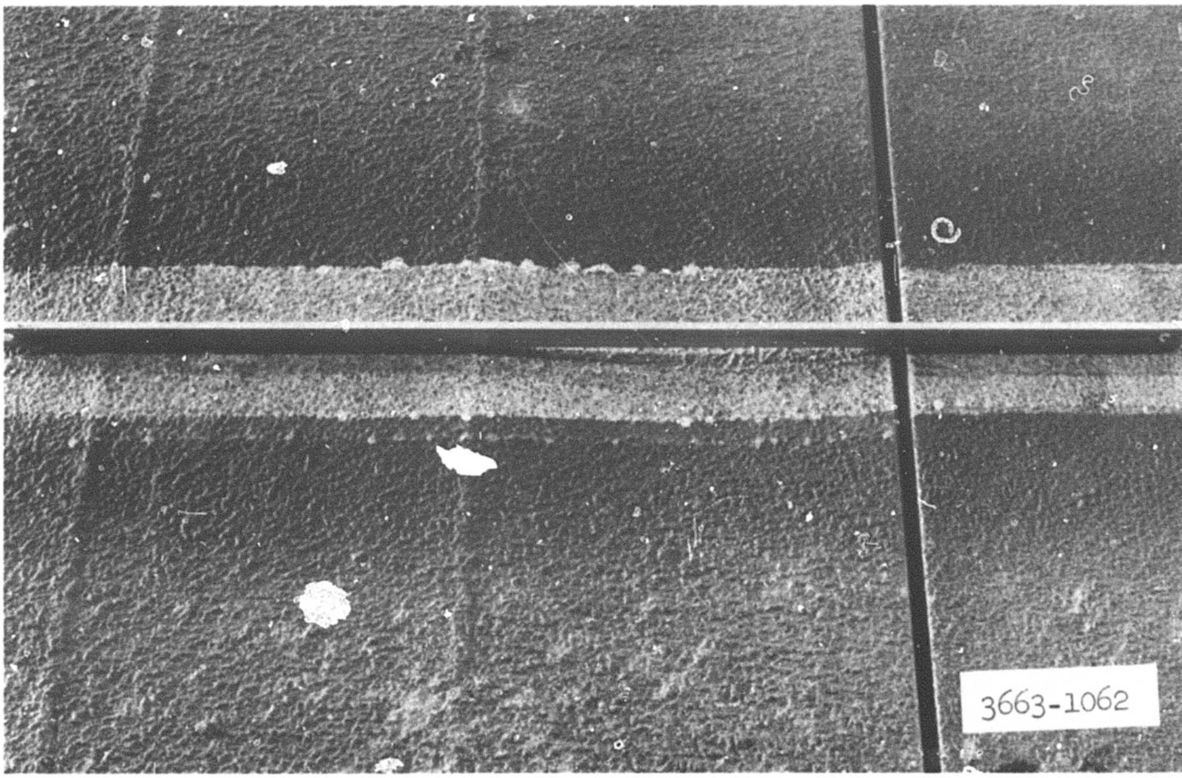
Photograph 14. Item 3, lane 1, after 188 coverages

Photograph 15. General view of item 4, lane 1, prior to traffic

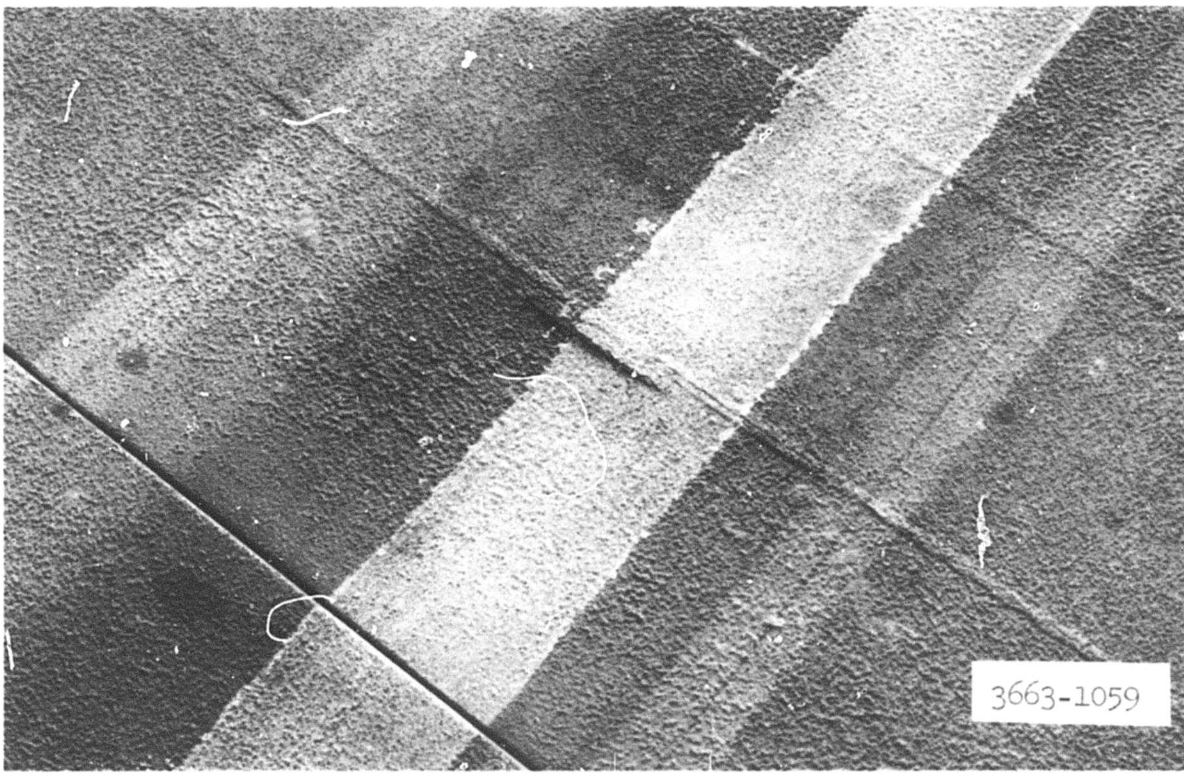


Photograph 16. General view of item 4, lane 1, after 188 coverages

Photograph 17. Item 1, lane 2, prior to traffic



Photograph 18. Dishing in surface as result of core damage, item 1, lane 2

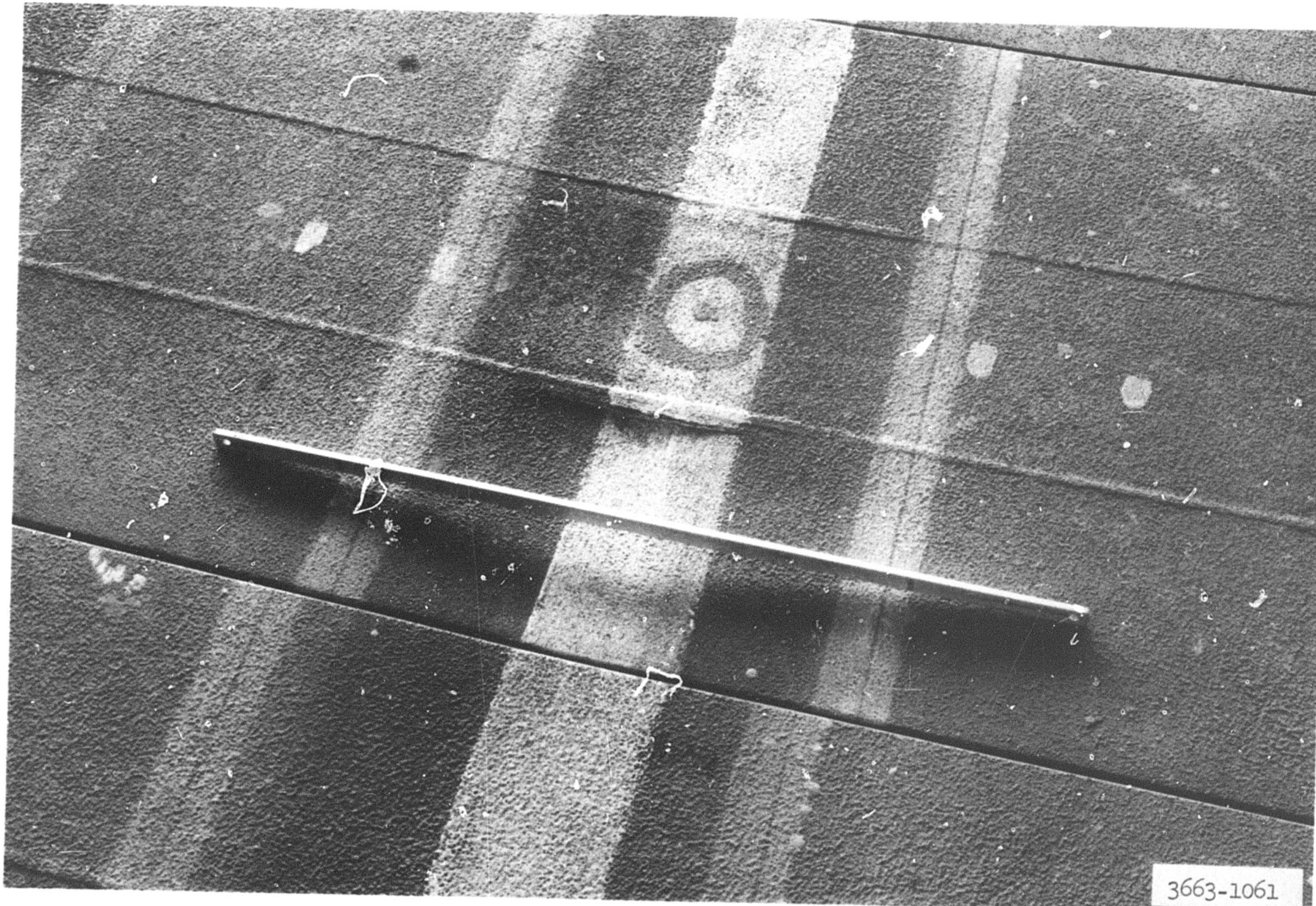


Photograph 19. Skin tear in plank 5 after 1000 passes, item 1, lane 2

Photograph 20. Item 1, lane 2, after 1000 passes

Photograph 21. Item 1, lane 2, after 1320 passes (failure)

Photograph 22. Item 2, lane 2, prior to traffic



Photograph 23. Skin tear due to core failure, item 2, lane 2

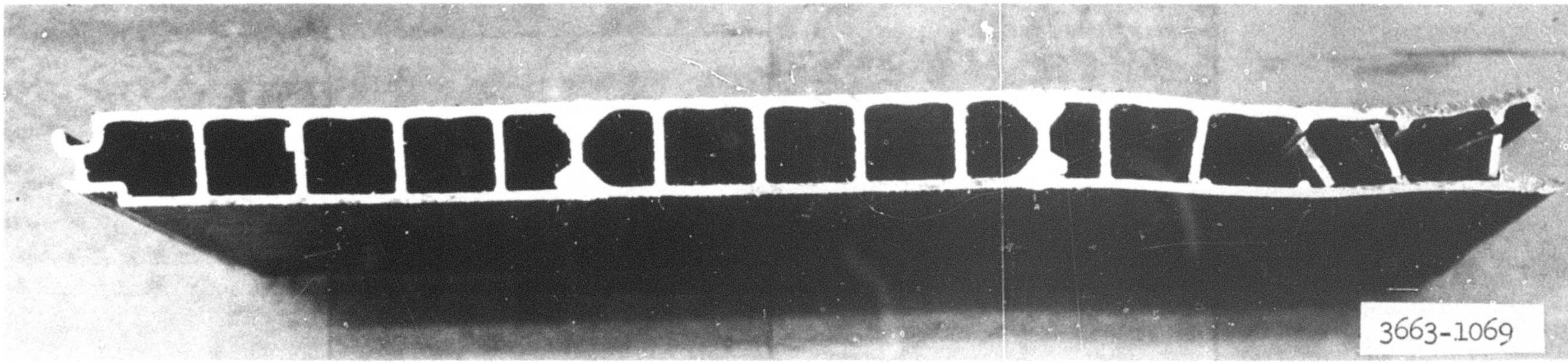
Photograph 24. Item 2, lane 2, after 1600 passes

Photograph 25. Item 3, lane 2, prior to traffic

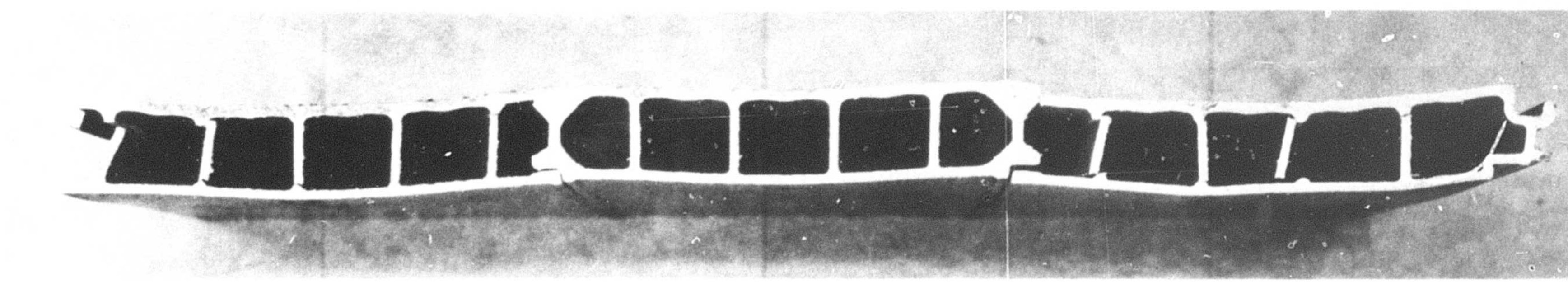
Photograph 26. Item 3, lane 2, after 1600 passes

Photograph 27. Item 4, lane 2, prior to traffic

Photograph 28. Item 4, lane 2, after 1600 passes

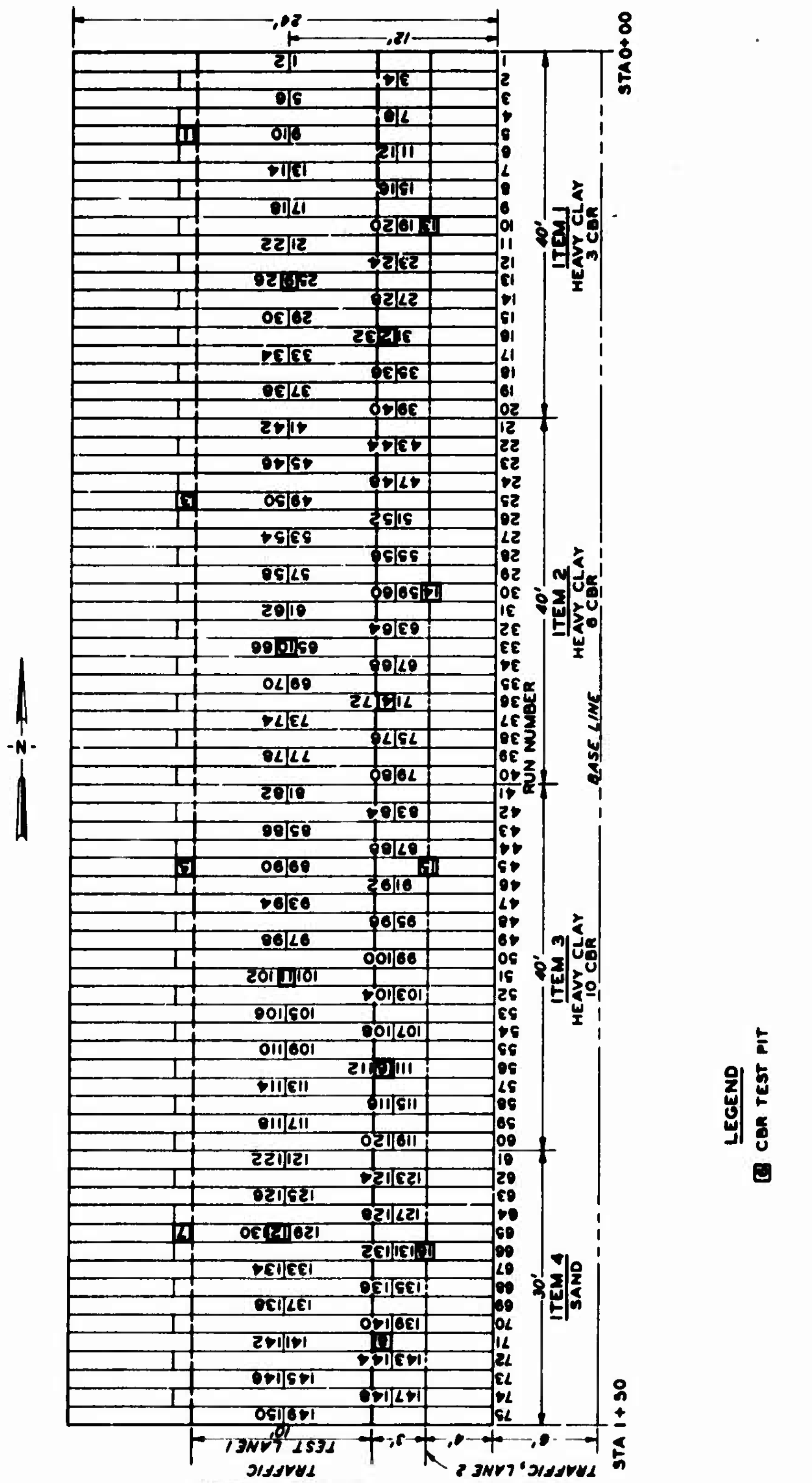


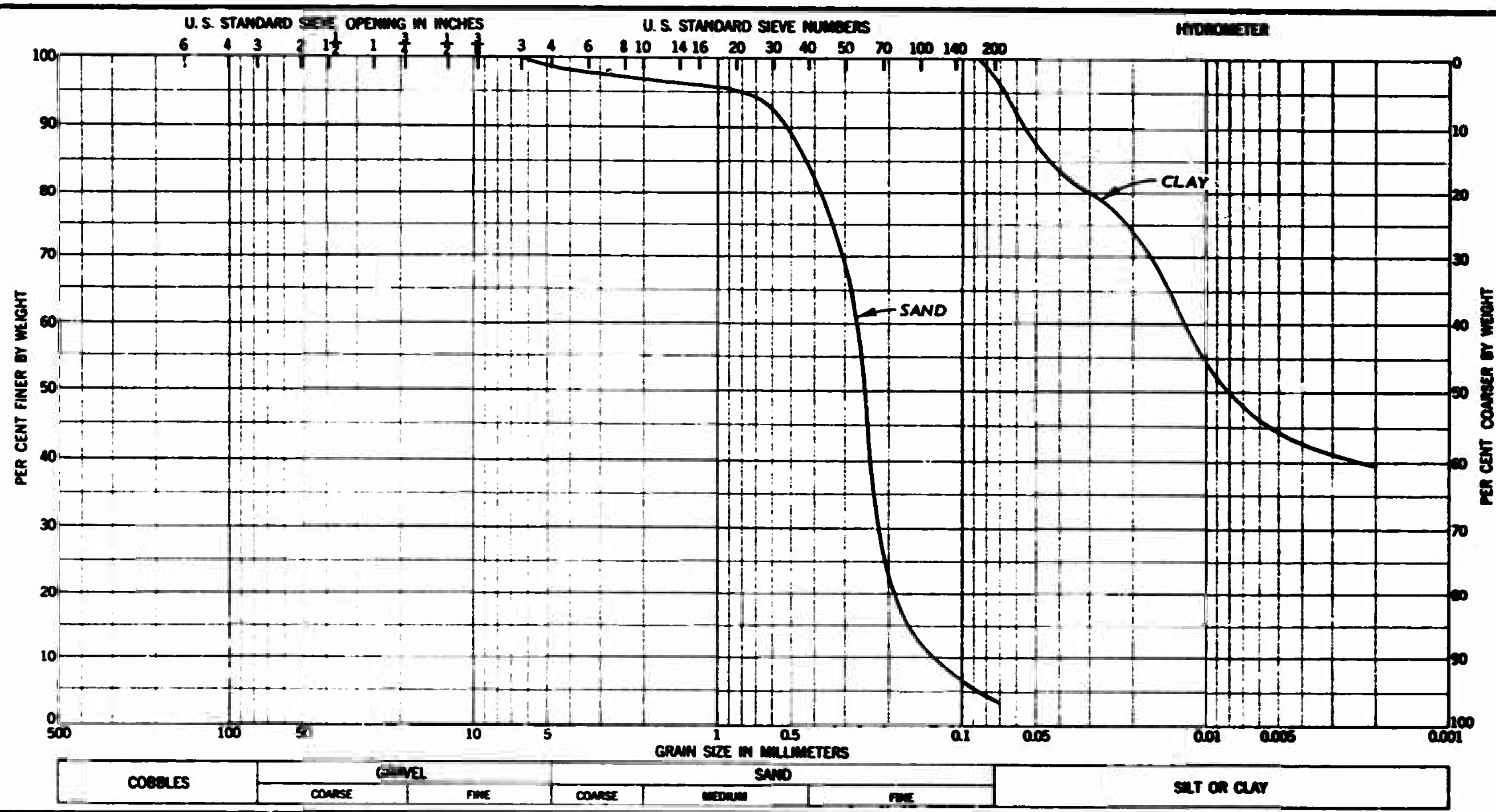
Photograph 29. Cut section of mat from uniform-coverage traffic test, showing core failure. The failed core was located directly adjacent to the joint in the preceding run



Photograph 30. Cut section of mat from single-line traffic lane showing core damage

TEST SECTION LAYOUT PLAN





Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		HEAVY CLAY (BUCKSHOT), CH		58	27	31
		SAND, SP		NONPLASTIC		

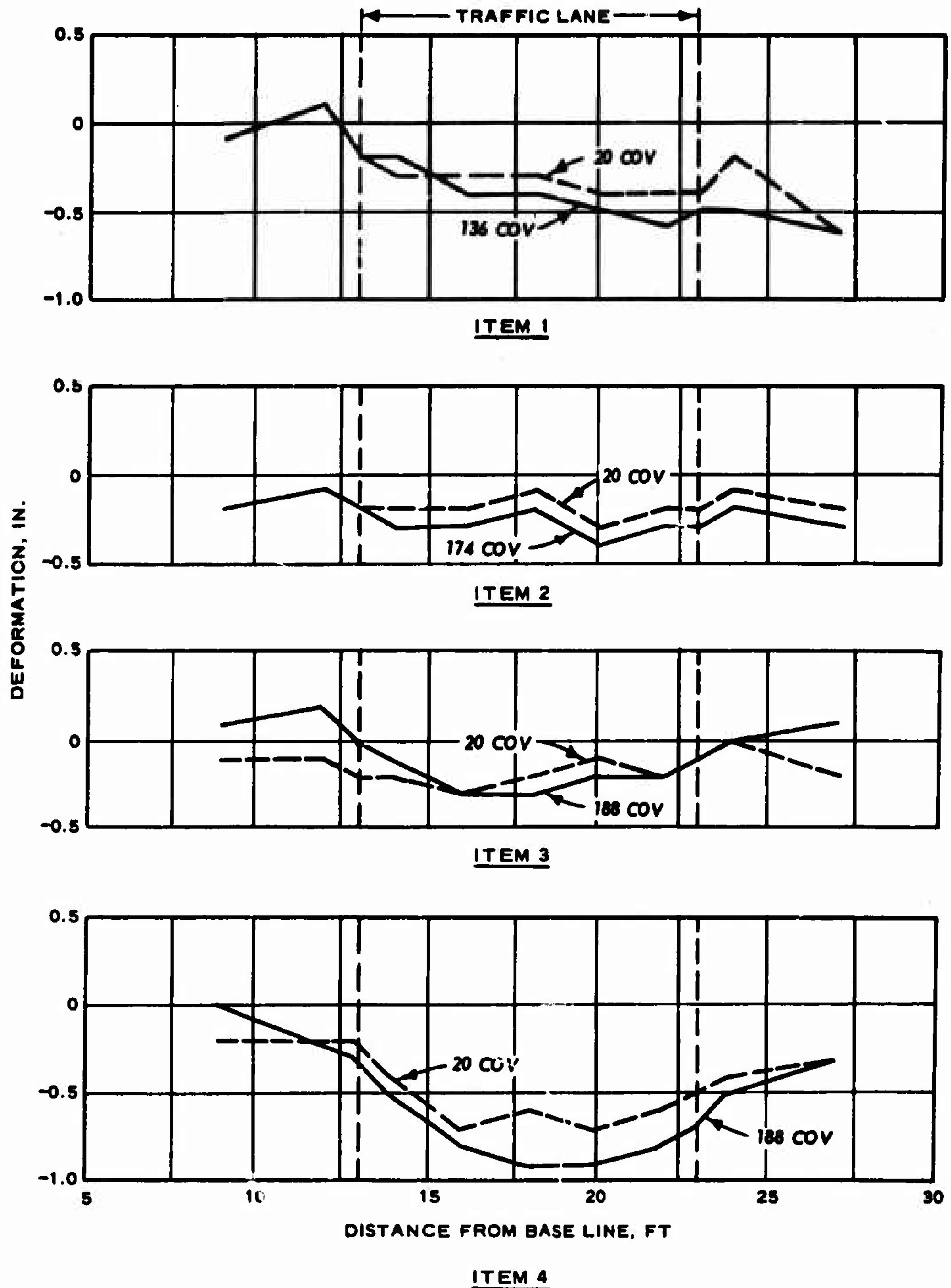
GRADATION CURVES

CLASSIFICATION DATA

SUBGRADE SOILS

WES FORM NO. 1241
SEPT. 1962

PLATE 2



PERMANENT MAT DEFORMATION

TEST LANE 1

UNIFORM-COVERAGE TRAFFIC

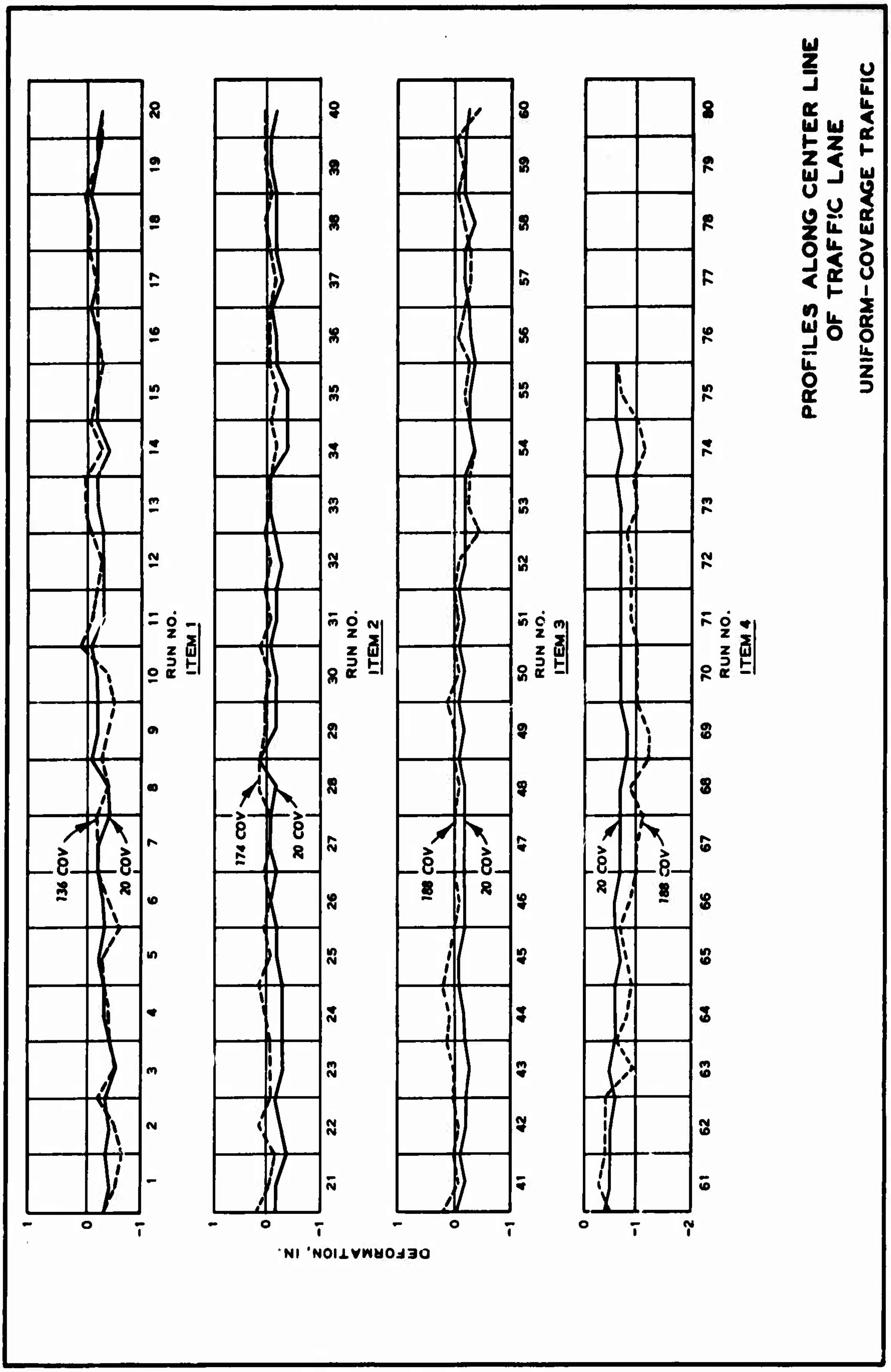
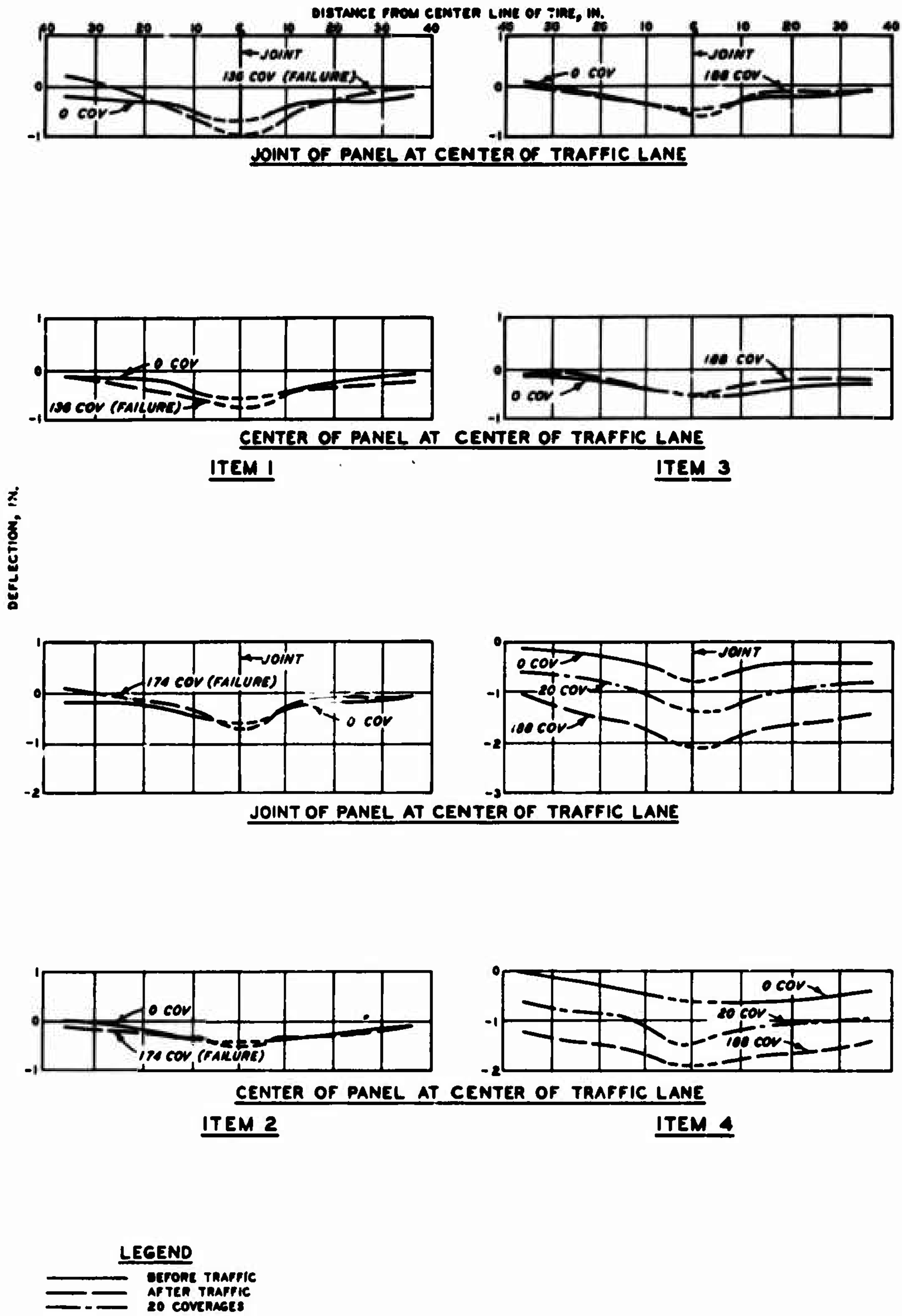

PROFILES ALONG CENTER LINE
OF TRAFFIC LANE
UNIFORM-COVERAGE TRAFFIC
DEFORMATION, IN.
RUN NO.
ITEM 1
ITEM 2
ITEM 3
ITEM 4
136 COV
20 COV
174 COV
20 COV
188 COV
20 COV
20 COV
188 COV

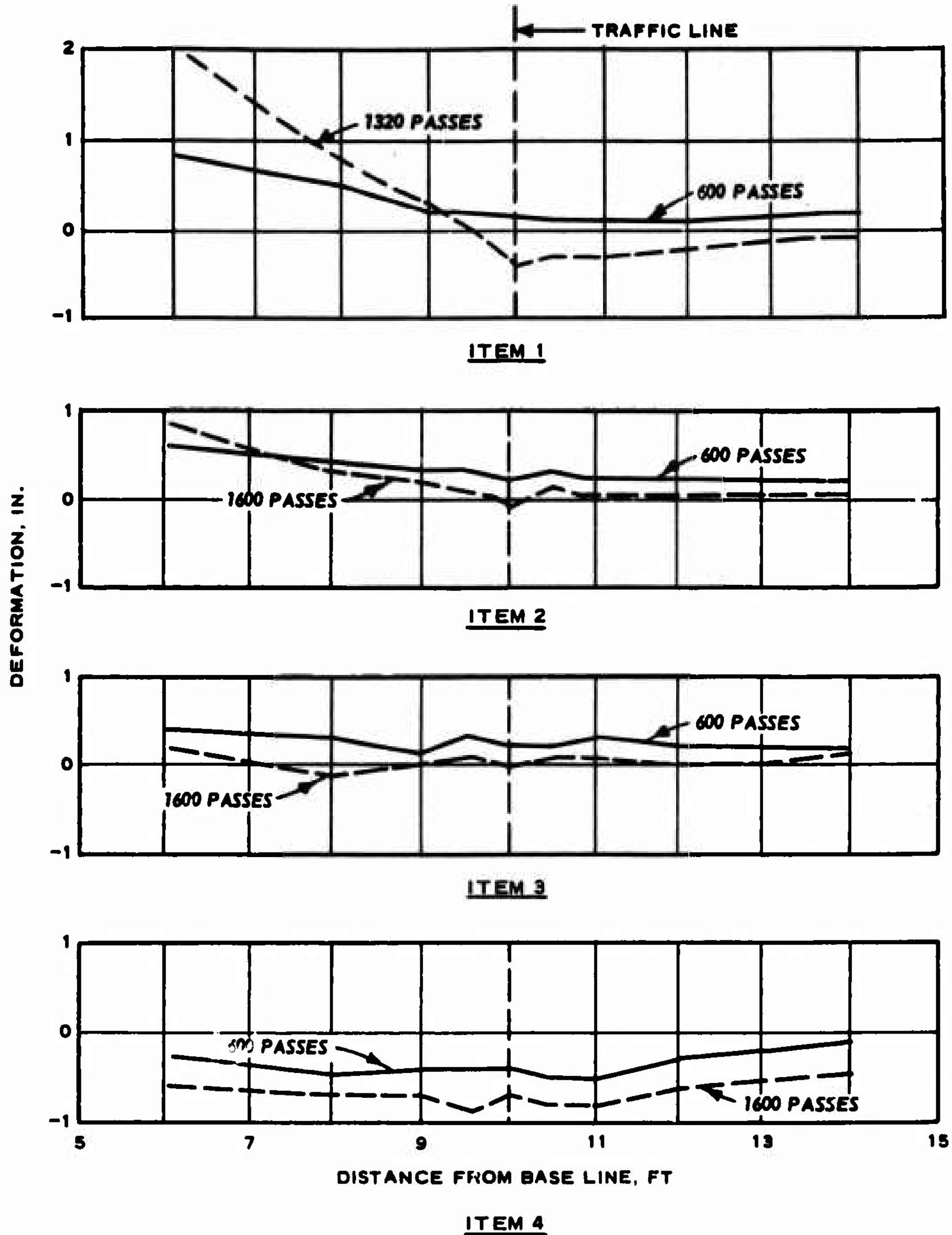
PLATE 4



ELASTIC DEFLECTION OF MAT

TEST LANE 1

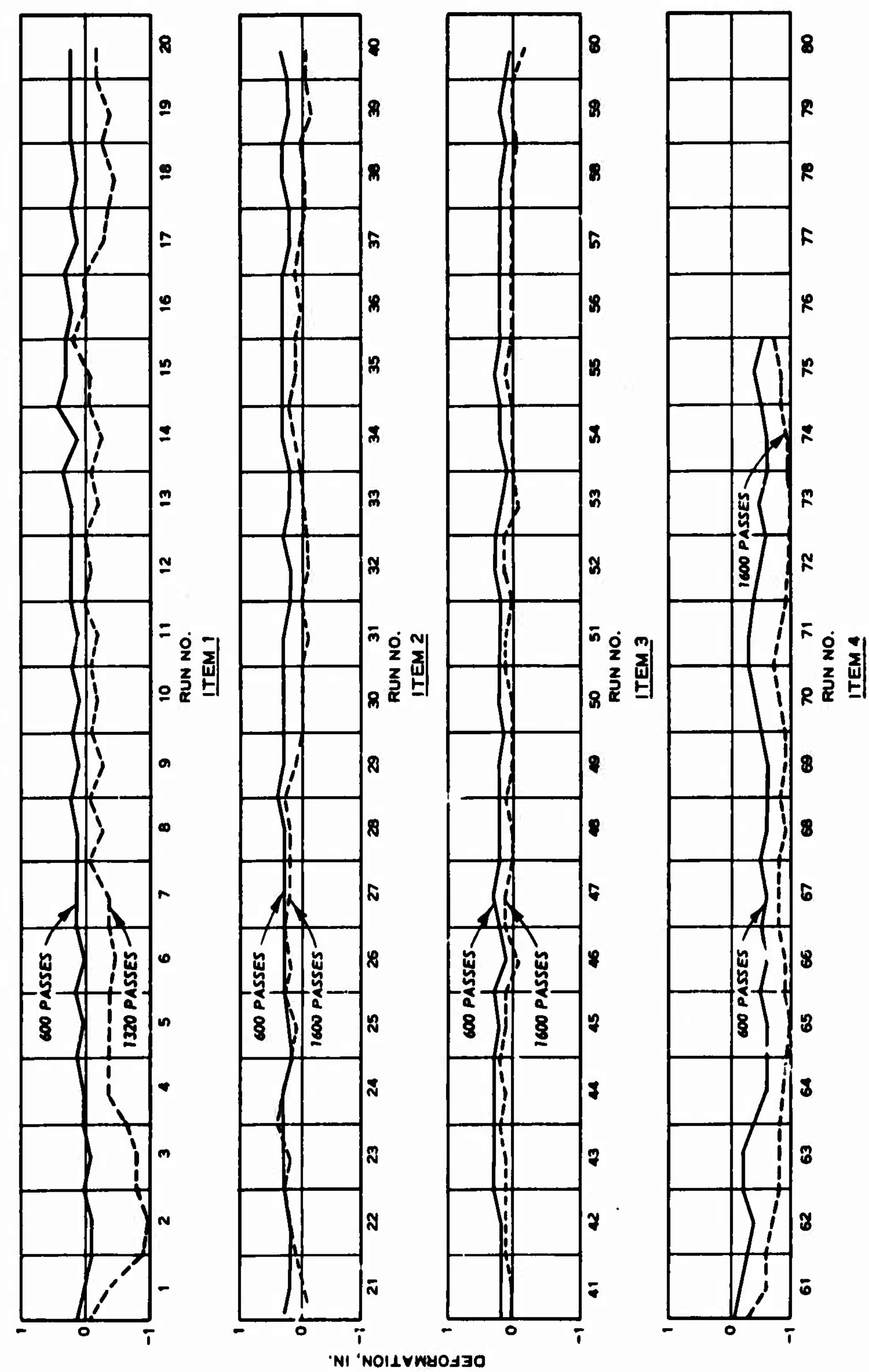
UNIFORM-COVERAGE TRAFFIC



PERMANENT MAT DEFORMATION

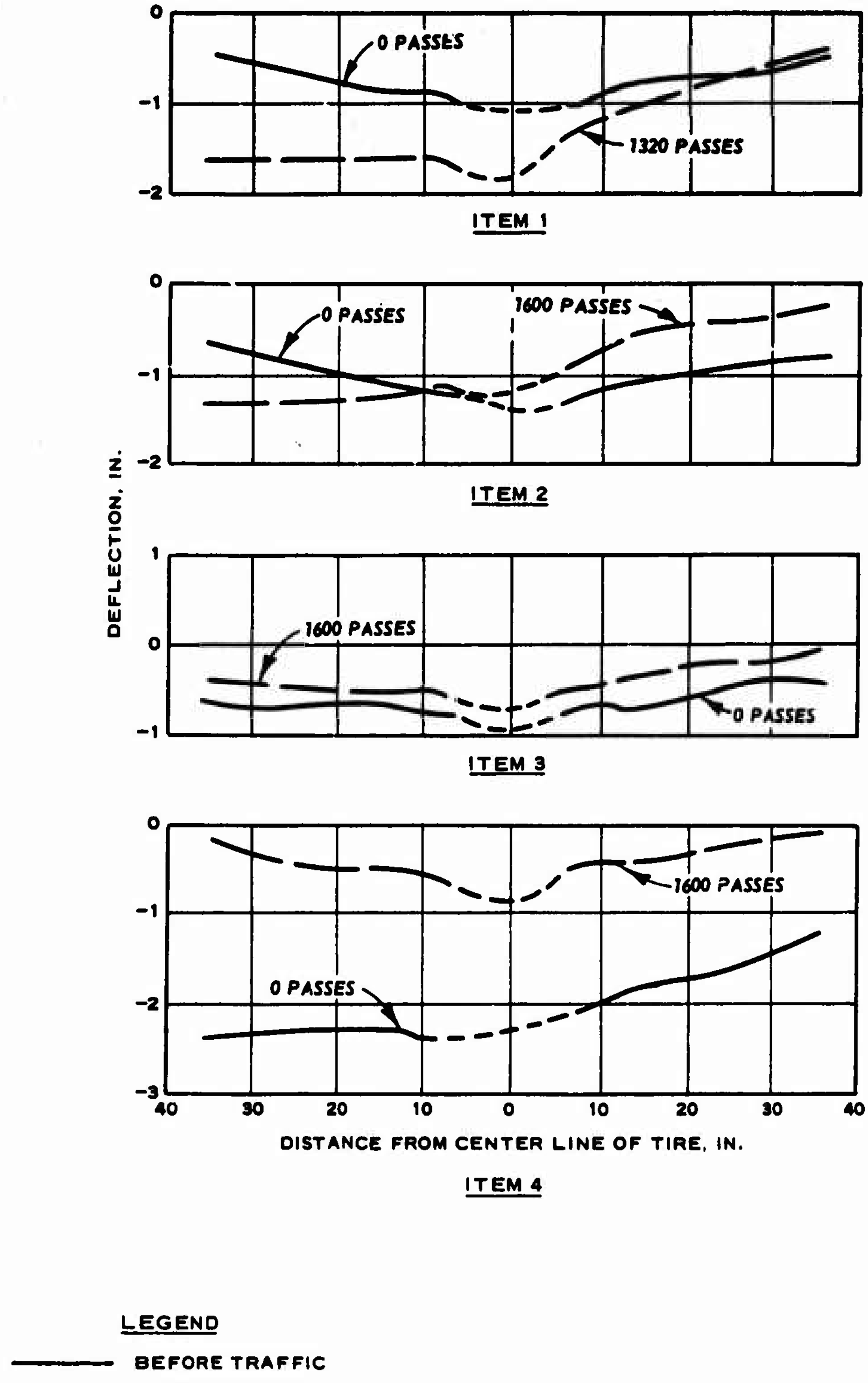
TEST LANE 2

SINGLE-LINE TRAFFIC



PROFILES ALONG CENTER LINE OF TRAFFIC LANE

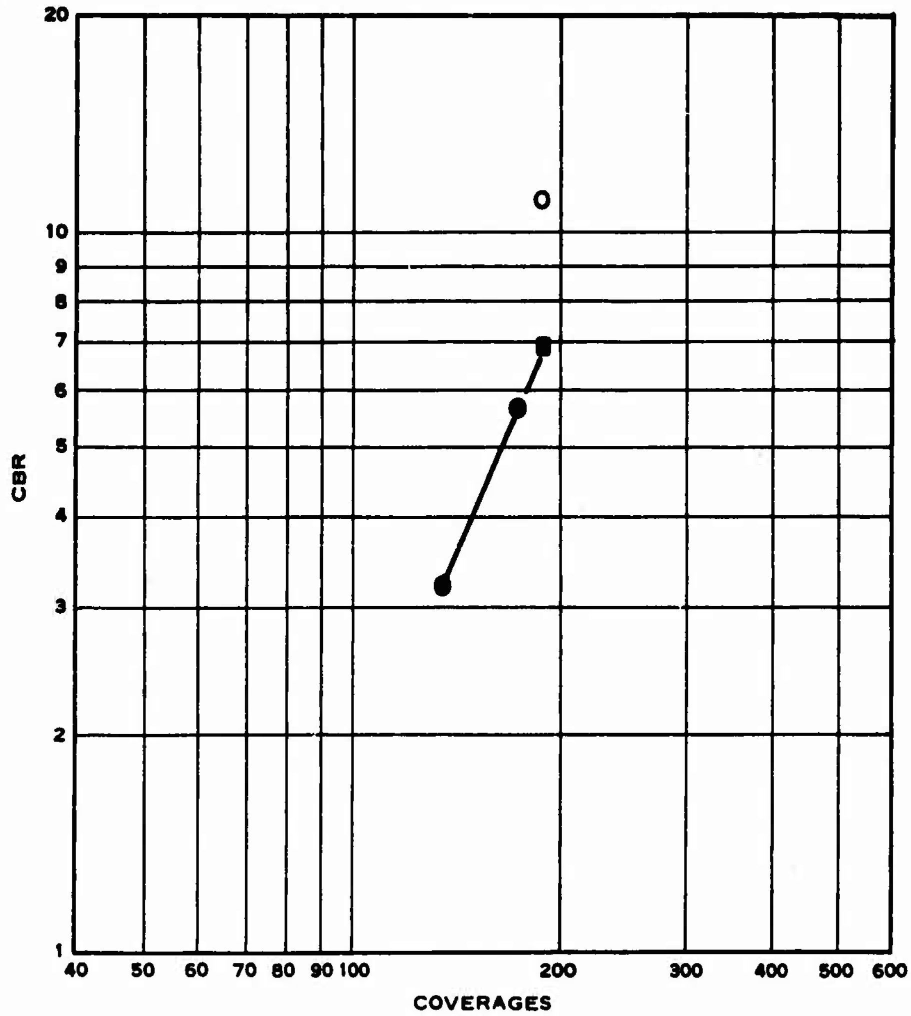
SINGLE-LINE TRAFFIC



ELASTIC DEFLECTION OF MAT

TEST LANE 2

SINGLE-LINE TRAFFIC



LEGEND

ACTUAL TEST DATA (FAILURE)

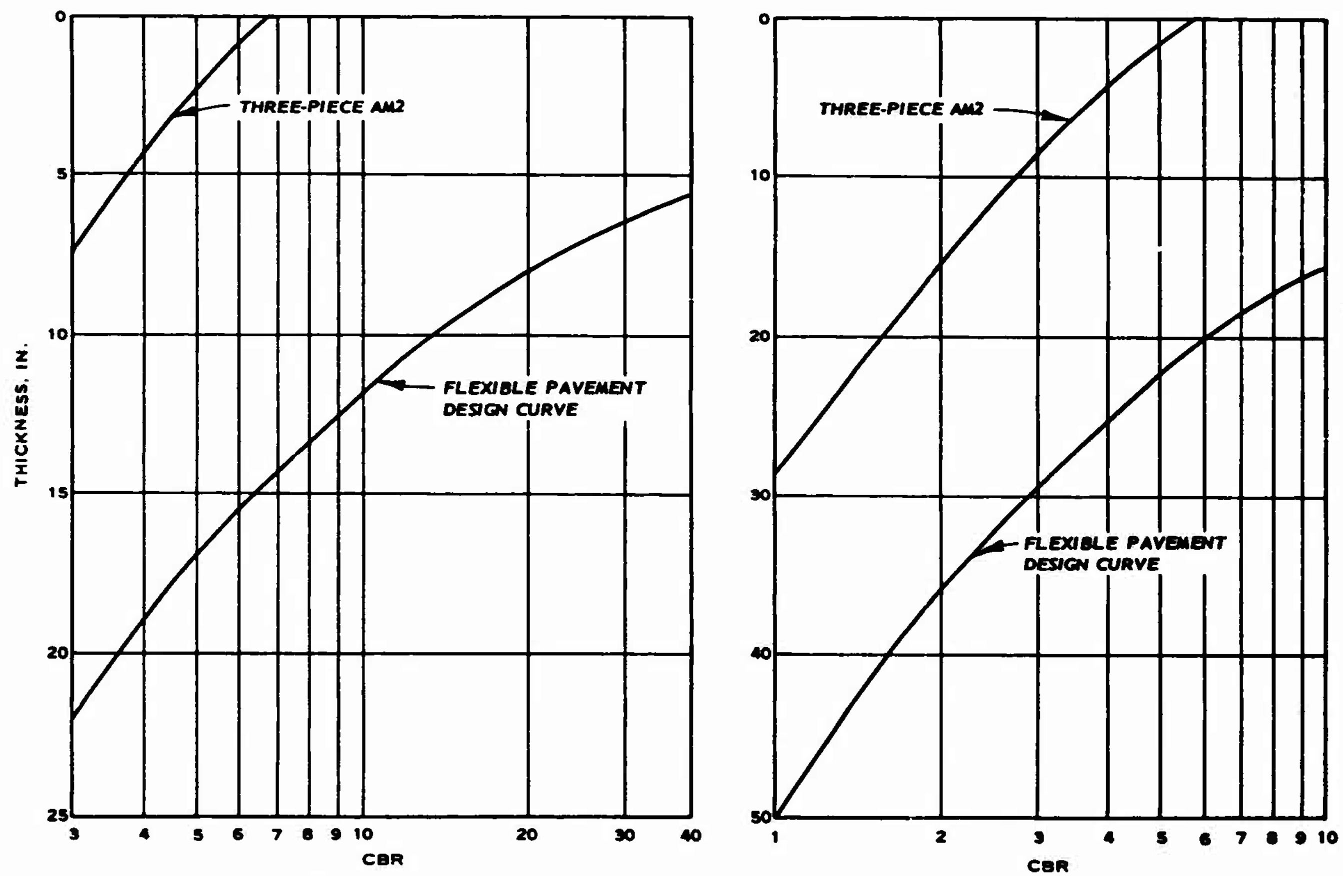
ACTUAL TEST DATA (NO FAILURE)

EXTRAPOLATED DATA

CBR VERSUS COVERAGES

UNIFORM-COVERAGE TRAFFIC

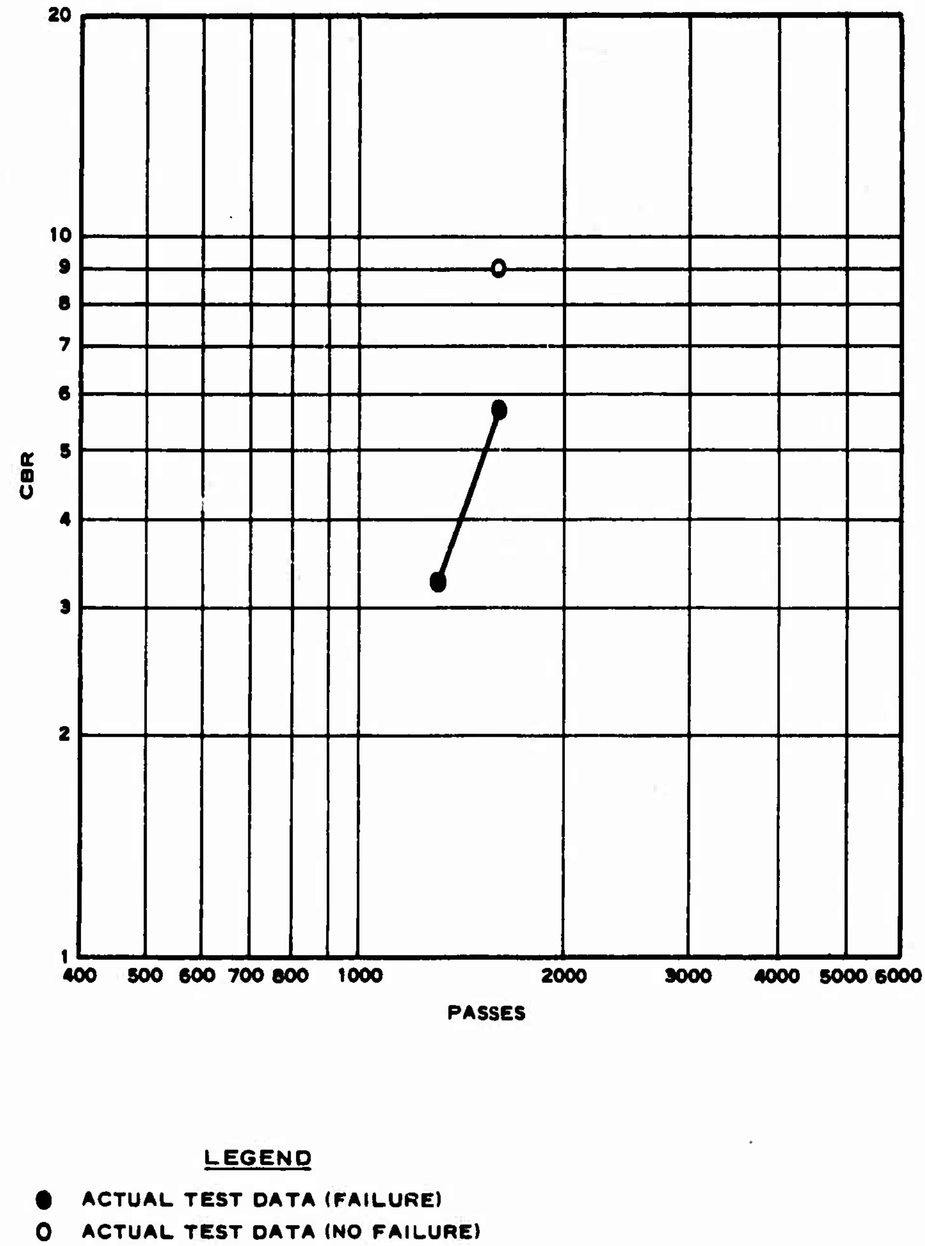
CLAY SUBGRADE



a. 188 COVERAGES

b. 1600 PASSES

CBR DESIGN CURVE
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE



CBR VERSUS PASSES

SINGLE-LINE TRAFFIC

CLAY SUBGRADE